45TH ANNUAL ISCE CONFERENCE
VIRTUAL EDITION
APRIL 28 - MAY 1, 2021

CONFERENCE CHAIR
PYOTR PLATONOVA, MD, PHD, FESC
LUND UNIVERSITY | SWEDEN

CONFERENCE CO-CHAIR
RAYMOND BOND, PHD
ULSTER UNIVERSITY | N. IRELAND

ISCE 2021 CONFERENCE SUPPORTERS

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PHILIPS HEALTHCARE
GE HEALTHCARE

GLOBAL INSTRUMENTATION
SCHILLER AG
MEDITRONIC
ZOLL MEDICAL CORPORATION
PHYSIO-CONTROL, NOW PART OF STRYKER
HILLROM
HEARTSCIENCES
VITALOGRAF
<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Session Title</th>
<th>Speaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:00 - 08:30</td>
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<td>Raymond Bond</td>
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<td>Peter MacFarlane</td>
</tr>
</tbody>
</table>

**Big Data Research**

<table>
<thead>
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<th>PDT</th>
<th>CEST</th>
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<th>Speaker</th>
</tr>
</thead>
</table>

**Poster Session 1**

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Session Title</th>
<th>Chair: Thomas Hilbel</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00 - 13:00</td>
<td></td>
<td>21:00 - 22:00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Wednesday, April 28

### Poster Session 1

<table>
<thead>
<tr>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzing ECG Using Pre-trained Image Processing Neural Networks</td>
<td>Saeed Babaeizadeh</td>
</tr>
<tr>
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<td>Laura Burattini</td>
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<td>The electro-anatomical pathway for normal and bundle branch block ECGs</td>
<td>Peter van Dam</td>
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<td>Neural networks for ischaemia detection: revolution or red herring? A systematic review and meta-analysis</td>
<td>Rob Brisk</td>
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<td>Jørgen K. Kanters</td>
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<td>Jana Svehlikova</td>
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<td>Pediatric Heart Rate Variability Preceding In-Hospital Cardiac/Pulmonary Arrest</td>
<td>Yu-He Zhang</td>
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<td>Annotation Protocol Designed to Improve Ventricular Tachycardia Identification during In-Hospital ECG</td>
<td>Michele M. Pelter</td>
</tr>
</tbody>
</table>
### Thursday, April 29

#### Atrial Substrate in Sinus Rhythm and Arrhythmia  
Chair: Pyotr Platonov, Co-Chair: Leif Sörnmo

<table>
<thead>
<tr>
<th>PDT</th>
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</tr>
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<tr>
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<td>17:00 - 17:30</td>
<td>Big Data and the P-wave</td>
<td>Claus Graff</td>
</tr>
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<td>08:30 - 09:00</td>
<td>17:30 - 18:00</td>
<td>Spectral Characterization of Atrial Fibrillation in the Surface ECG - Past, Present and Future</td>
<td>Martin Stridh</td>
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<td>09:10 - 09:40</td>
<td>18:10 - 18:40</td>
<td>The AF Toolbox and the Swiss AF Study</td>
<td>Ramun Schmid</td>
</tr>
<tr>
<td>09:40 - 10:10</td>
<td>18:40 - 19:10</td>
<td>Invasive and non-invasive substrate characterisation of AF</td>
<td>Uli Schotten</td>
</tr>
</tbody>
</table>

#### Selected Oral Abstracts Session  
Chair: Claus Graff, Co-Chair: Peter van Dam

<table>
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<td>Prehospital ST-depression and T-wave Inversion are Associated with New Onset Heart Failure in Individuals Transported by Ambulance for Suspected Acute Coronary Syndrome</td>
<td>Jessica Zegre-Hemsey</td>
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<td>10:50 - 11:20</td>
<td>19:50 - 20:20</td>
<td>Identification of ion channel blocks by continuous T vector velocity effect profiles in CiPA studies</td>
<td>Werner Bystricky</td>
</tr>
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<td>11:20 - 11:50</td>
<td>20:20 - 20:50</td>
<td>RightQT: Accurate QT correction method based on the exact dynamical dependence between RR and QT intervals</td>
<td>Esa Rasanen</td>
</tr>
<tr>
<td>11:50 - 12:00</td>
<td>20:50 - 21:00</td>
<td><strong>Business Session</strong></td>
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</tr>
</tbody>
</table>

#### Poster Session 2  
ECG/Holter handling and signal processing  
Chair: Jørgen Kanters

<table>
<thead>
<tr>
<th>PDT</th>
<th>CEST</th>
<th>Title</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>12:10 - 13:40</td>
<td>21:10 - 22:40</td>
<td><strong>Poster Session 2</strong></td>
<td><strong>Poster Session 2</strong></td>
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<tr>
<td>Title</td>
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<tr>
<td>Record Segmentation to Speed Up Long-Term ECG Analysis Algorithms</td>
<td>Ben Bailey</td>
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<td>Continues Live Measurement of Heart Rate and RR Intervals Using the new Integrated Features of the Chromium Internet Browser Family</td>
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<td>Richard E. Gregg</td>
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<td>A Full-Automatic Software Program for Analyzing ECG in Holter Applications</td>
<td>Antoun Khawaja</td>
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<td>Regression or pseudo-inverse: which method should be preferred when developing inverse linear ECG-lead</td>
<td>Daniel Guldenring</td>
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<td>A New Graphical Method for Reporting Performance Results of Diagnostic Tests</td>
<td>John Wang</td>
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<tr>
<td>Clinical and Heart Rate Variability Feature Analysis of Pre-ablation AF patients Leading to Recurrence</td>
<td>Javier Saíz-Vivo</td>
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<td></td>
</tr>
<tr>
<td>Mutations in the Genes Encoding Cardiac Ion Channels May Contribute in Life-Threatening Arrhythmias in Patients with Hypertrophic Cardiomyopathy</td>
<td>Elena Zaklyazminskaya</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Wearable Update

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Details</th>
</tr>
</thead>
<tbody>
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<td>17:00 - 17:30</td>
<td>mHealth and Arrhythmia Management: Perspectives from the 2021 ISHNE/HRS/EHRA/APHRS Collaborative Statement</td>
<td><em>Niraj Varma</em></td>
</tr>
<tr>
<td>08:30 - 09:00</td>
<td>17:30 - 18:00</td>
<td>Wearables: European perspective (ESC WG e-Cardiology report)</td>
<td><em>Magnus Jensen</em></td>
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</tbody>
</table>

### Kenichi Harumi Plenary Address

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Details</th>
</tr>
</thead>
<tbody>
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<td>09:10 - 10:10</td>
<td>18:10 - 19:10</td>
<td>ISCE &amp; Electrocardiography: Past, Present &amp; Future</td>
<td><em>David Albert</em></td>
</tr>
</tbody>
</table>

### Jos Willems Early Career Investigator Competition

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>10:50 - 11:20</td>
<td>19:50 - 20:20</td>
<td>Electrocardiographic Differences in Acute Ischemic Responses to Exercise and Pharmacological Stress</td>
<td><em>Brian Zenger</em></td>
</tr>
<tr>
<td>11:20 - 11:50</td>
<td>20:20 - 20:50</td>
<td>Electrocardiographic Imaging (ECGI) can Improve Endocardial Mapping for Wavefront Reconstruction and PVC Localization</td>
<td><em>Wilson Good</em></td>
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</tbody>
</table>

### Poster Session 3

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Details</th>
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<tr>
<td>12:30 - 13:30</td>
<td>21:30 - 22:30</td>
<td>ECGi / Ischemia / QT</td>
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<tr>
<td>Title</td>
<td>Author</td>
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<tr>
<td>ECGI for Cardiac Resynchronization Therapy: Technical Challenges and Clinical Benefits</td>
<td>Danila Potyagaylo</td>
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<tr>
<td>Improving Non-invasive Prediction of the PVC Origin Using the Standard 12-lead ECG</td>
<td>Roger Abächerli</td>
<td></td>
<td></td>
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<tr>
<td>Characteristics on the Admission 12-Lead ECG Prognostic of Re-Infarction and Death among UA/NSTEMI Patients: A Protocol and Preliminary Results for a Systematic Review &amp; Meta-Analysis</td>
<td>Dillon J. Dzikowicz</td>
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<td>Significant Improvement in Automated STEMI Detection by Modeling the ST Segment</td>
<td>Reza Firoozabadi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagnostic and Prognostic Value of ST-segment Deviations in Patients with Suspected Myocardial Infarction and Right Bundle Branch Block</td>
<td>Yama Fakhri</td>
<td></td>
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<td>A Composite Signal Quality Index for Analysis of the Large ECG Datasets</td>
<td>Sara Mariani</td>
<td></td>
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<td>Characterization of Impaired Ventricular Repolarization by Quantification of QT Delay After Heart Rate Changes in Stress Test</td>
<td>Cristina Pérez Martínez</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Saturday, May 1

## Cardiogenetics
**Chair: Wojciech Zareba, Co-Chair: Fabio Badilini**

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
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</tr>
</thead>
<tbody>
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<td>T wave morphology in Long QT Syndrome</td>
<td>Alan Surgue</td>
</tr>
<tr>
<td>08:30 - 09:00</td>
<td>17:30 - 18:00</td>
<td>17:30 - 18:00</td>
<td>Heart Rate and QT Variability in the Long QT Syndrome</td>
<td>Wojciech Zareba</td>
</tr>
<tr>
<td><strong>Break</strong></td>
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<td>Identification of hERG blockade by machine learning</td>
<td>Laura Burratini</td>
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<td>09:40 - 10:10</td>
<td>18:40 - 19:10</td>
<td>18:40 - 19:10</td>
<td>Depolarization disturbances in ARVC</td>
<td>Pyotr Platonov</td>
</tr>
</tbody>
</table>

## ECG Imaging
**Chair: Suave Lobodzinski, Co-Chair: Peter van Dam**

<table>
<thead>
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<td>20:20 - 20:50</td>
<td>Normal Cine-electrocardiogram: can we standardize the ECG to the cardiac anatomy?</td>
<td>Peter van Dam</td>
</tr>
</tbody>
</table>

## Closing ceremony
**Jean-Philippe Couderc, Pyotr Platonov, Raymond Bond, Michele Pelter, Mary Carey**

<table>
<thead>
<tr>
<th>Time</th>
<th>PDT</th>
<th>CEST</th>
<th>Session</th>
</tr>
</thead>
</table>
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>An Overview of Machine Learning: Techniques, Pitfalls and Trust Issues</td>
<td>6</td>
</tr>
<tr>
<td>Author(s): Raymond Bond</td>
<td>6</td>
</tr>
<tr>
<td>ECG Pre-processing and Feature Engineering for Machine Learning</td>
<td>7</td>
</tr>
<tr>
<td>Author(s): Dewar Finlay</td>
<td>7</td>
</tr>
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<td>How to Evaluate and Deploy a Machine Learning Algorithm</td>
<td>8</td>
</tr>
<tr>
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<td>8</td>
</tr>
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<td>9</td>
</tr>
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<td>Author(s): Peter W. Macfarlane</td>
<td>9</td>
</tr>
<tr>
<td>University of Glasgow</td>
<td></td>
</tr>
<tr>
<td>Artificial Intelligence and Machine Learning in Software as a Medical Device- FDA perspective</td>
<td>10</td>
</tr>
<tr>
<td>Author(s): Loriano Galeotti</td>
<td>10</td>
</tr>
<tr>
<td>Prognostic Value of AI-predicted ECG-Age. The CODE (Clinical Outcomes in Digital Electrocardiography) Stud</td>
<td>11</td>
</tr>
<tr>
<td>Author(s): Antonio Luiz P. Ribeiro (a), Antônio H. Ribeiro (a), Emilly M Lima (a), Manoel Horta Ribeiro (b), Gabriela M.M. Paixão (a), Derick M. Oliveira (a), Paulo R. Gomes (a), Wagner Meira Jr. (a) , and Thomas B. Schön(c)</td>
<td>11</td>
</tr>
<tr>
<td>Big Data Reveals Insights for Lead Importance in ECG Interpretation</td>
<td>12</td>
</tr>
<tr>
<td>Author(s): Ting Yang, PhD, Richard E. Gregg, MS, Saeed Babaeizadeh, PhD Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA</td>
<td>12</td>
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<td>13</td>
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<td>13</td>
</tr>
<tr>
<td>Identification of hERG blockade by machine learning</td>
<td>15</td>
</tr>
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<td>Author(s): Micaela Morettini, PhD, Eugenia De Remigis, BSc, Agnese Sbrollini, PhD, Ilaria Marcantoni, MSc, Laura Burattini, PhD</td>
<td>15</td>
</tr>
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<td>17</td>
</tr>
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<td>18</td>
</tr>
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<td>Author(s): Peter M. Van Dam, PhD (1,3), Emanuela T. Locati MD, PhD (2), Giuseppe Cicone, MD (2), Valeria Borrelli, PhD (2), Vincenzo Santinelli, MD (2), Gabriele Vicedomini, MD (2), Michelle M Monasky, PhD (2), Emanuele Micaglio, MD (2), Luigi Giannelli, MD (2), Valerio Mecarocci, MD (2), Zarko Calovic, MD (2), Carlo Pappone, MD, PhD (2)</td>
<td>18</td>
</tr>
</tbody>
</table>
“What was AI thinking?”: Explainable deep learning in reading of 12-lead ECGs for detecting V1 and V2 electrode misplacement

Author(s): Khaled Rjoob, MSc (a), Raymond Bond, PhD (a), Dewar Finlay, PhD (a), Victoria McGilligan, PhD (b), Stephen J Leslie, PhD (c), Daniel Guldenring, PhD (d), Ali Rababah, MSc (a), Aleeha Ifikhar, MSc (a), Charles Knoery, MSc (c), Anne McShane, MSc (e), Aaron Peace, PhD (f).

Pediatric Heart Rate Variability Preceding In-Hospital Cardiac/Pulmonary Arrest

Author(s): Yu-He Zhang, PhD (a), Eric D. Helfenbein, MS (a), Saeed Babaeizadeh, PhD (a), Jeffery Chan, BA (b), Lynda J. Knight, MSN, BSN, RN, CPN (b), Felice Su, MD (c)

Deep Learning Neural Network can measure ECG intervals and amplitudes accurately

Author(s): Jorgen K. Kanters (a), Steven A. Hicks (b), Jonas L. Isaksen (a), Niels Grarup (a), Niels-Henrik Holstein Rathlou (c), Jonas Ghouse (a), Gustav Ahlberg (a), Morten Salling Olesen (a), Allan Linneberg (a), Christina Ellervik (d), Torben Hansen (a), Claus Graff (e), Paal Halvorsen (b), Michael Riegler (b).

The Importance of Residual PVC Offset Correction for Inverse Localization of PVC Origin Using a Single Dipole

Author(s): Jana Svehlikova, PhD (a), Jan Zelinka, MS (a), Miroslav Haska, MS (a), Beata Ondrusova, MS (a), Katarina Kromkova, MS (b), Peter Hlivak MD, PhD (b), Robert Hatala, MD, PhD (b), Milan Tysler, PhD (a)

Big data and the P-wave

Author(s): Claus Graff

Spectral Characterization of Atrial Fibrillation in the Surface ECG - Past, Present and Future

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RightQT: Accurate QT correction method based on the exact dynamical dependence between RR and QT intervals

Author(s): 
CLINICAL AND HEART RATE VARIABILITY FEATURE ANALYSIS OF PRE-ABLATION AF PATIENTS LEADING TO RECURRENCE

Author(s): Javier Saiz-Vivo, MSc (a,b), Valentina D A Corino, PhD (b), Mirko de Melis, PhD (a), Luca T Mainardi, PhD (b)

A New Graphical Method for Reporting Performance Results of Diagnostic Tests

Author(s): John Wang, MS

Annotation Protocol Designed to Improve Ventricular Tachycardia Identification during In-Hospital ECG

Author(s): Michele M. Pelter, RN, PhD (1), Mary G. Carey, RN, PhD,(2) Salah Al-Zaiti, RN, PhD,(3) Jessica Zegre-Hemsey,(4) Claire Sommargren, RN, PhD,(1b) David Mortara,(1c) PhD, Fabio Badilin, PhD,(1d)

Continues Live Measurement of Heart Rate and RR Intervals Using the new Integrated Features of the Chromium Internet Browser Family

Author(s): Thomas Hilbel (1,3), Wolfram Stein (1), Gwendolyn Mayer (2), Jobst-Hendrik Schultz (2), Hugo A Katus (1)

Mutations in the genes encoding cardiac ion channels may contribute in life-threatening arrhythmias in patients with hypertrophic cardiomyopathy

Author(s): E. Zaklyazminskaya, MD, PhD,(a), N. Chakova, BSc, PhD, (b), S. Komissarova, MD, PhD, (c), S. Niyazova, BSc, (b), A. Shestak, BSc, (a), S. Dzemeshkevich, MD, PhD,(a)

Record Segmentation to Speed Up Long-Term ECG Analysis Algorithms

Author(s): Ben Bailey, Saeed Babaeizadeh Advanced Algorithm Research Center, Philips

Regression or pseudo-inverse - which method should be preferred when developing inverse linear ECG-lead transformations?

Author(s): Daniel Guldenring, MEng, PhD (a), Ali Rababah, MSc (b), Dewar D. Finlay, BSc, PhD (b), Raymond R. Bond, BSc, PhD (b), Alan Kennedy, BSc, PhD (b), James McLaughlin, PhD (b)

ECG Reading Differences Demonstrated on Two Databases

Author(s): Richard E. Gregg MS (a), Ting Yang PhD (a), Stephen W. Smith, MD (b), Saeed Babaeizadeh PhD (a)

A Full-Automatic Software Program for Analyzing ECG in Holter Applications

Author(s): Antoun Khawaja, PhD

Electrocardiogram report system: the importance of decision-making tools

Author(s): Paulo R. Gomes, BSc (a), Gabriela M. Paix (a), Gabriela M. Paix (a), MSc. MD (a), Emilly M Lima, MSc., Milena S. Marcolino, PhD MD(a), Leonardo B. Ribeiro BSc(a), Graziela Chequer, PhD MD(a), Maria B.M. Alkmim, MSc(a),., Peter W. Macfarlane, PhD (b), Antonio L. Ribeiro , PhD(a)

mHealth and Arrhythmia Management: Perspectives from the 2021 ISHNE/HRS/EHRA/APHRS Collaborative Statement
Wearables: European perspective (ESC WG e-Cardiology report) 49

ISCE & Electrocardiography: Past, Present & Future 50

Novel Approaches to ECG Feature Selection for Dimensionality Reduction to Optimize ACS Detection using Only the Prehospital 10-second, 12-Lead ECG 51

Electrocardiographic Differences in Acute Ischemic Responses to Exercise and Pharmacological Stress 53

Electrocardiographic Imaging (ECGI) can Improve Endocardial Mapping for Wavefront Reconstruction and PVC Localization 54

The odyssey of acute myocardial infarction detection in automated ECG interpretation algorithms: The Denominator Challenge 56

Characterization of impaired ventricular repolarization by quantification of QT delay after heart rate changes in stress test 58

 Significant Improvement in Automated STEMI Detection by Modeling the ST Segment 60

A Composite Signal Quality Index for Analysis of the Large ECG Datasets 61

Diagnostic and prognostic value of ST-segment deviations in patients with suspected myocardial infarction and right bundle branch block 63
ECGI for Cardiac Resynchronization Therapy: Technical Challenges and Clinical Benefits
Author(s): D. Potyagaylo (1), M. Chmelevsky (1,2), M. Budanova (2), S. Zubarev (2), T. Treshkur (2), D. Lebedev (2)

Improving non-invasive prediction of the PVC origin using the standard 12-lead ECG
Author(s): Roger Abächerli (a,d), Peter Michael van Dam (a), Ivo Strebel (b), Sven Knecht (b), Florian Spies (b), Martim Kastelein (c), Michael Kühne (b), Christian Sticherling (d), Tobias Reichlin (b)

Characteristics on the Admission 12-Lead ECG Prognostic of Re-Infarction and Death among UA/NSTEMI Patients: A Protocol and Preliminary Results for a Systematic Review & Meta-Analysis
Author(s): Dillon J. Dzikowicz BS, RN, Mary G. Carey PhD, RN, FAHA

T wave morphology in Long QT Syndrome
Author(s): Alan Sugrue

Heart Rate and QT Variability in the Long QT Syndrome
Author(s): Wojciech Zareba, MD, PhD, Jean-Philippe Couderc, PhD, MBA, Jean Xia, PhD

Identification of hERG blockade by machine learning
Author(s): Micaela Morettini, PhD, Eugenia De Remigis, BSc, Agnese Sbrollini, PhD, Ilaria Marcantoni, MSc, Laura Burattini, PhD

Depolarization disturbances in ARVC
Author(s): Pyotr G Platonov, MD, PhD

Computerized ECG analyses of Brugada Syndrome
Author(s):

ECGI for Cardiac Resynchronization Therapy: Technical Challenges and Clinical Benefits
Author(s): Peter M. Van Dam, PhD, (1,3), Machteld J Boonstra, MSc, (1), Emanuela T. Locati MD, PhD (2), Peter Loh, MD, PhD (1)

Normal Cine-electrocardiogram: Can We Standardize the ECG to the Cardiac Anatomy?
Author(s): Peter M. Van Dam (PhD) 1,3, Machteld J Boonstra (MSc) 1, Emanuela T. Locati MD (PhD) 2, Peter Loh (MD PhD) 1

Mapping Ventricular Arrhythmias with ECG Imaging
Author(s): S. Suave Lobodzinski
An Overview of Machine Learning: Techniques, Pitfalls and Trust Issues

**Author(s):** Raymond Bond

**Presentation Date and Time:** Wed Apr 28 08:00:00 UTC 2021

This talk will present the basics of machine learning including definitions, processes and the typical algorithms used to analyse ECGs. The talk will be accessible to delegates from clinical, technological and industrial backgrounds. Beyond covering the general data science pipeline from data preparation, feature engineering and modelling, the talk will emphasise important issues that data-driven algorithms have and will discuss the importance of integrating domain knowledge. Key issues relating to automation bias (over trusting algorithms), AI explainability and accountability will be discussed. We will also explore the need for ‘explanation user interfaces’ in the next generation of automated ECG interpretation systems. The talk will suggest that providing insight and understanding is arguably more important than providing a mere prediction."
Automated interpretation of the 12-lead ECG remains the core theme in the application of computers in Electrocardiology. A number of commercially available 12-lead ECG interpretation programs have been at the forefront of the state of the art for many years. Traditionally, automated interpretation of ECGs has relied on a reasonable degree of pre-processing of the acquired signals to allow extraction of relevant information in the form of ECG ‘features’. This in turn facilitates diagnostic interpretation and subsequent diagnostic statements to be generated.

More recently there has been renewed interested in developing new approaches to automated ECG interpretation through the application of Artificial Intelligence and, in particular, deep learning. Deep learning algorithms rely on large volumes of data to generate diagnostic algorithms. These algorithms have been shown to yield superior levels of diagnostic performance when compared to earlier acritical intelligence techniques.

In this tutorial we provide an overview of traditional approaches to ECG pre-processing and feature extraction in automated ECG interpretation and show the sharp contrast to how input data is handled in emerging deep learning based algorithms.
How to Evaluate and Deploy a Machine Learning Algorithm

**Author(s):** Joel Xue

**Presentation Date and Time:** Wed Apr 28 09:10:00 UTC 2021

**Background:**

**Methods:**

**Results:**

**Conclusions:**
An overview of recent studies on the use of machine learning for ECG analysis

Author(s): Peter W. Macfarlane
University of Glasgow

Presentation Date and Time: Wed Apr 28 09:40:00 UTC 2021

There has been a recent explosion of manuscripts dealing with the use of Machine Learning in the field of automated ECG interpretation. Many of the studies refer to a very specific aspect such as prediction of atrial fibrillation or even estimation of a low ejection fraction, while fewer papers at the other extreme report on standard 12 lead ECG interpretation.

This presentation will look at a small selection of papers to provide a flavour of the breadth of applications in the field and will offer comments on the results. The design of a study and the style of reporting results will also be considered.

Preliminary comments are that it can be difficult to fully comprehend every article unless the reader is expert both in Machine Learning and Electrocardiography. It might also be said that the Gold Standard in some studies requires further consideration. In addition, there is a lack of examples in the published literature of correct or incorrect outputs from an algorithm based on machine learning.

The pros and cons of this approach to ECG interpretation will also be summarised briefly.
Artificial intelligence (AI)- and machine learning (ML)-based technologies have the potential to transform healthcare by deriving new and important insights from the vast amount of data generated during the delivery of healthcare every day. Example high-value applications include earlier disease detection, more accurate diagnosis, identification of new observations or patterns on human physiology, and development of personalized diagnostics and therapeutics. This talk will discuss some aspects of the current ML/AI-based technologies applied to cardiac diagnostics algorithms in Software as a Medical Device.
**Prognostic Value of AI-predicted ECG-Age. The CODE (Clinical Outcomes in Digital Electrocardiography) Study**

**Author(s):** Antonio Luiz P. Ribeiro (a), Antônio H. Ribeiro (a), Emilly M Lima (a), Manoel Horta Ribeiro (b), Gabriela M.M. Paixão (a), Derick M. Oliveira (a), Paulo R. Gomes (a), Wagner Meira Jr. (a) , and Thomas B. Schön(c).

(a) Universidade Federal de Minas Gerais, Belo Horizonte, Brazil  
(b) École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland  
(c) University of Uppsala, Uppsala, Sweden

**Presentation Date and Time:** Wed Apr 28 10:50:00 UTC 2021

**Background:** Aging affects the electrocardiogram (ECG) with higher incidence of abnormalities in older patients. A recent study suggests that an ECG-age can be predicted by artificial intelligence (AI) and can be used as a measure of cardiovascular health. Since the prognosis impact of this measure is unknown, we evaluate if ECG-age predicted by AI is a risk factor for overall mortality.

**Methods:** The CODE dataset consists of 2,322,513 ECGs from 1,676,384 Brazilian patients (2010-17), and was split using a 16-1-3 ratio in training, validation and test datasets. A Deep Convolutional Neural Network was trained in order to predict the age of the patient based solely on ECG 12-lead tracings. Death was ascertained using probabilistic linkage with the Brazilian mortality database. We divided the patients into three groups according to the ECG-age > 7y observed age, ECG-age < 7y observed age and ECG-age +- 7y observed age (reference group). We assessed the prognostic value of ECG-age using Cox regression, adjusted by sex and observed age.

**Results:** Test sample consists 348,276 patients (515,349 exams), mean age 50.74 (SD: 19.82). During a mean follow-up was 3.67y, 12,422 deaths occurred. The mean predicted ECG-age was 52.52 (SD: 16.23) years with a mean absolute error of 7.05 (SD: 5.59) years (y); the model R2 was 0.81. Patients with a difference >7y between ECG and real age had higher mortality (HR: 1.82 [95CI: 1.72-1.93], p<0.001). Patients with ECG age <7y the real age had lower mortality (HR: 0.88 [95CI: 0.85-0.92], p<0.001).

**Conclusions:** ECG-age, predicted by AI, can be used as a predictor for overall mortality. Further studies should help to understand the putative value of ECG-age in addition, and in comparison, to standard scores of cardiovascular risk.
Big Data Reveals Insights for Lead Importance in ECG Interpretation

Author(s): Ting Yang, PhD, Richard E. Gregg, MS, Saeed Babaeizadeh, PhD Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA

Presentation Date and Time: Wed Apr 28 11:20:00 UTC 2021

Background: Not every lead contributes equally in interpretation of a standard 12-lead 10-second ECG. For some abnormalities, we could infer which lead plays an important role by its placement as well as cardiac electrophysiology. For some other abnormalities, the reader’s past experiences may be the main source of the lead importance. There are also abnormalities in which the lead importance is not clear either from electrophysiology or experience. Therefore, it may be beneficial to develop an algorithm to quantify the lead importance in the reading of ECGs.

Methods: One representative beat per ECG lead was constructed for 146,000 interpreted ECGs collected retrospectively in a single hospital in North America. De-identified ECGs that might have come from the same patient were identified based on age and gender. An algorithm was developed to find the top 5 ECGs in the database that had the most similar morphology to the query ECG, independently for each lead. This algorithm guaranteed that ECGs from the same patient as the query ECG will not be included in the search results, and all similar ECGs will be from different patients. For each lead, the query ECG was interpreted based on the weighted average voting on the top 5 similar ECGs by applying a variety of thresholds. For each type of abnormality, we found the threshold that maximized the median F1 score of sensitivity and positive predictive value among all 12 leads. Finally, the F1 score of each lead at this chosen threshold was defined as the importance value for that lead.

Results: We applied the algorithm of quantifying lead importance to many types of abnormality. For most, the lead importance confirmed what expert ECG readers already know. However, it also revealed new insights. For example, in the detection of long QT interval (LQT), ventricular pre-excitation (VPE) and right ventricular hypertrophy (RVH), the importance of lead aVR ranked first in LQT and VPE and second in RVH. In the detection of right atrial enlargement, lead III and aVL were the top 2 most important leads. These findings, in part, help to justify the usefulness of augmented leads.

Conclusions: Although not all leads contribute equally to interpreting an ECG, it is possible and useful to quantify their importance in a large database. Such information may be useful in selecting only the most important leads to screen for a specific abnormality, for example using wearable patches.
Neural networks for ischaemia detection: revolution or red herring? A systematic review and meta-analysis

Author(s): Rob Brisk, MBBC, Raymond Bond, PhD, Dewar Finlay PhD, James McLaughlin, PhD, Alicja Piadlo, MBBCh, Michael Jennings, MEng, David J McEneaney, MD

Computing and engineering Department, Ulster University, Jordanstown, Northern Ireland

Presentation Date and Time: Wed Apr 28 12:00:00 UTC 2021

Background: Artificial neural networks (ANNs) are machine learning (ML) algorithms that have been investigated as a means of automatically detecting acute myocardial ischaemia from electrocardiogram (ECG) signals since the early 1990s. In recent years, there has been renewed interest in ANNs as the basis for “deep learning” (DL), which is cited as the leading edge in artificial intelligence (AI). The purpose of this review is to ascertain what progress has been made in detecting acute myocardial infarction (AMI) from ECG signals using ANNs and DL to date.

Methods: The titles, abstracts and keywords of full-text articles on Medline, Scopus and Web-of-Science were searched using the following terms: ((myocardial infarction OR ischaemia) AND (neural network OR deep learning) AND (electrocardiogram OR ECG)). The searches were performed in November 2019. Abstracts of all search results were screened. All studies specifically pertaining to the use of ANNs to detect AMI from ECG signals were reviewed in full. Data was extracted and a quality score was constructed around the QUADAS-2 framework. Studies with a quality score above 4 whose endpoint was relevant to the review question were included in the meta-analysis. To account for different balances between sensitivity and specificity, the meta-analysis concentrated on the F1 score (the harmonic mean of the sensitivity and the positive predictive value).

Results: The search process generated 196 results; 45 studies were reviewed in full; 27 were excluded from the meta-analysis due to quality concerns; 6 studies were excluded because their end points did not align with the meta-analysis. The 12 studies included in the meta-analysis were published between 1994 and 2019; 3 were prospective; 9 were retrospective. A total of 8480 test subjects were included. Disease prevalence was 23%. The average F1 score (with 95% confidence intervals) was 0.79 (0.72-0.85). A population weighted average F1 score was calculated at 0.83. Further sub-analyses were undertaken (see attached figures).

Conclusions: AMI detection by ANN analysis of ECG signals is likely to be a promising research avenue but the current high-quality evidence base in this area is sparse. Of the studies reviewed in full, 60% did not meet quality criteria. Linear regression analysis of quality scores revealed that average quality has decreased over time. Only 11% of studies reviewed were
undertaken prospectively. A minority of studies discussed issues regarding transparency of ANNs, which is likely to be important for future applications.
Identification of hERG blockade by machine learning

Author(s): Micaela Morettini, PhD, Eugenia De Remigis, BSc, Agnese Sbrollini, PhD, Ilaria Marcantoni, MSc, Laura Burattini, PhD

Presentation Date and Time: Wed Apr 28 12:00:00 UTC 2021

Background: Blockade of hERG potassium channel induced by some pharmacological treatments could predispose to development of Torsade-de-Pointes (TdP). However, drugs that block hERG may also block other ion channels (i.e. sodium and calcium), hence mitigating TdP risk. Thus, in order to obtain an improved TdP risk prediction when designing new drugs, there is the need to study multiple distinct ionic channels which are responsible for TdP. Blockade of hERG affects T-wave morphology on the electrocardiogram (ECG) and a machine-learning approach, based on artificial neural network (ANN), has been recently proposed for the ECG-based classification of such blockade. This study aimed to extend this approach to the detection of hERG potassium channel blockade independent from concomitant sodium and/or calcium blockade.

Methods: The data were taken from the ECG Effects of Ranolazine, Dofetilide, Verapamil, and Quinidine in Healthy Subject. Physionet database; they consisted of median vector magnitude (VM) beats of 22 healthy subjects receiving a single 500 mg dose of dofetilide (pure hERG potassium channel blocker) and, in a separate day, 1500 mg of ranolazine (hERG and calcium/sodium currents blocker). A total of twenty-eight VM beats were considered for each subject, relative to time points ranging from 0.5 hr before to 14.0 hr after dofetilide or ranolazine administration (fourteen VM beats for each drug). For each VM, changes in the two indexes ERD30% and TS/A, accounting for the early and the late phases of repolarization, respectively, were computed as difference between values at each postdose timepoint and the predose timepoint. Thus, the dataset contained 286 ERD30% and TS/A pairs for the dofetilide administration and 286 ERD30%-TS/A pairs for the ranolazine administration. Firstly, the overall 572 ERD30%-TS/A pairs and secondly, only the 286 ERD30%-TS/A pairs related the dofetilide administration were randomly partitioned into training (40%), validation (10%), and test (50%) sets and used as inputs of a two layer feedforward ANN with 18 neurons in the hidden layer and two target classes: high blockade (HB) and low blockade (LB). For the test, the two receiver operating characteristics (ROC) were compared by using Venkatraman test (p<0.05).

Results: Test-set area under the ROC was 0.90 and 0.91 in dofetilide+ranolazine and dofetilide dataset, respectively; no statistical difference between the two ROC was observed (p=0.26). Accuracy was 0.82 and 0.92 in dofetilide+ranolazine and dofetilide dataset, respectively.

Conclusions: The proposed machine-learning approach proved to be reliable for the detection
of hERG potassium-channel blockade independent from concomitant sodium and/or calcium blockade.
Analyzing ECG Using Pre-trained Image Processing Neural Networks

**Author(s):** Saeed Babaeizadeh, PhD

Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA

**Presentation Date and Time:** Wed Apr 28 12:00:00 UTC 2021

**Background:** Computer algorithms for electrocardiograms (ECG) interpretations have existed for decades. However, there is still an unmet need to improve their performance. The main challenge in using Artificial Intelligence (AI) for ECG processing is the availability of large-scale annotated datasets. One common technique to address this challenge is transfer learning, in which one fine-tunes an existing network to learn a new task using a much smaller training dataset. Deep learning for image processing has been thoroughly studied by many researchers. Therefore, there already exist a few publicly available well-trained neural networks for image processing. These networks cannot directly analyze ECG because ECG waveforms are time-series not images. We propose a novel technique that generates an image from a 10-second 12-lead ECG recording in a way that both temporal and spatial information are preserved.

**Methods:** First, we construct one representative beat per ECG lead. Then, the 12 representative beats are converted to vectorcardiography (VCG) beats, each representing the heart vector in one of the 3 dimensions. We then represent each of the VCG beats as one of the 3 layers in a red-green-blue (RGB) image. For transfer learning, we utilized publicly-available AlexNet which has been trained on over a million images. We fine-tuned AlexNet to classify the morphology of an ECG recording as normal or abnormal. This was done by replacing the final layers of the pre-trained network, and then training the new network using VCG images. Our fine-tuning dataset contained 64,984 normal and 29,979 abnormal recordings, each reviewed by one cardiologist. If the diagnosis identified any abnormality in the ECG morphology, we labelled it abnormal. The abnormal cases included bundle branch block, short or prolonged PR interval, left or right ventricular hypertrophy, axis deviation, abnormal T wave, ST depression or elevation, low voltage, abnormal or missing P wave, infarct, left atrial enlargement, atrioventricular block, conduction delay, short or prolonged QT interval, poor R wave progression, ventricular preexcitation, and other abnormal morphology.

**Results:** The validation dataset contained 20,993 normal and 6,496 abnormal recordings. Defining a positive event as calling a recording normal, our technique achieved 82.4% sensitivity and 93.7% positive predictive value. Considering the simplicity of the technique, and the diversity of the dataset, this is impressive.

**Conclusions:** A few well-designed neural networks for image processing already exist in public domain. By intelligently converting multi-lead diagnostic ECG recordings to an image, these modern networks can efficiently be leveraged for ECG analysis.
The electro-anatomical pathway for normal and bundle branch block ECGs

Author(s): Peter M. Van Dam, PhD (1,3), Emanuela T. Locati MD, PhD (2), Giuseppe Ciconte, MD (2), Valeria Borrelli, PhD (2), Vincenzo Santinelli, MD (2), Gabriele Vicedomini, MD (2), Michelle M Monasky, PhD (2), Emanuele Micaglio, MD (2), Luigi Giannelli, MD (2), Valerio Mecarocci, MD (2), Zarko Calovic, MD (2), Carlo Pappone, MD, PhD (2)

(1) Department of Cardiology, University Medical Center Utrecht, The Netherlands
(2) Department of Arrhythmology and Electrophysiology, IRCCS Policlinico San Donato, Milano, Italy
(3) ECG Excellence BV, Nieuwerbrug aan den Rijn, Netherlands

Presentation Date and Time: Wed Apr 28 12:00:00 UTC 2021

Background: Conventional ECG based diagnosis of bundle branch block (BBB) in patients can be ambiguous. Left BBB can be difficult to detect in patients with left ventricular hypertrophy, whereas the definition of incomplete and complete right BBB is solely based on ECG waveforms and not on the electro-physiological activation of the heart. In this feasibility study we propose and evaluate the sensitivity of a new inverse ECG (iECG) tool, visualizing and classifying the average electro-anatomical pathway of the cardiac activation.

Methods: We developed a new inverse ECG method (iECG), to study the cardiac activation pathway by deriving the mean temporal spatial isochrone (mTSI) from the recorded 12-lead ECG. The mTSI describes the trajectory of the average electro-anatomical pathway within the cardiac anatomy. This enables the quantification of the activation progression to specific cardiac areas, such as the RVOT to the left free wall. A total of 62 of ECGs were analyzed divided in six groups. The ECG data was obtained from the certified Physionet PTB Diagnostic ECG Database. The cases included in the study were selected based on ECG morphology, i.e. normal, iRBBB, RBBB, and LBBB.

Results: Each of the ECGs were then classified using a) the cardiac anatomical mTSI direction of the terminal QRS segment and the ST segment, b) the mTSI trans-cardiac ratio and, c) the spatial location of the mTSI. 93% of the Normal ECGs were classified correctly, the remaining ECGs did deviate from the normal waveform, but also did not match any of the other classifications. All (i)RBBB, and LBBB ECG waveforms were classified correctly.

Conclusions: This study shows that the iECG technology is able to improve the detection and the understanding of the normal and left and right bundle branch block pattern. This electro-anatomical view on the ECG might help to obtain a better definition of the conduction disturbances represented by the ECG wave patterns.
“What was AI thinking?”: Explainable deep learning in reading of 12-lead ECGs for detecting V1 and V2 electrode misplacement

Author(s): Khaled Rjoob, MSc (a), Raymond Bond, PhD (a), Dewar Finlay, PhD (a), Victoria McGilligan, PhD (b), Stephen J Leslie, PhD (c), Daniel Guldenring, PhD (d), Ali Rababah, MSc (a), Aleeha Iftikhar, MSc (a), Charles Knoery, MSc (c), Anne McShane, MSc (e), Aaron Peace, PhD (f).

(a) Faculty of Computing, Engineering & Built Environment, Ulster University, Northern Ireland, UK.
(b) Faculty of Life & Health Sciences, Centre for Personalised Medicine, Ulster University, Northern Ireland, UK.
(c) Department of Diabetes & Cardiovascular Science, University of the Highlands and Islands, Centre for Health Science, Inverness, UK.
(d) HTW Berlin, Wilhelminenhofstr. 75A, 12459 Berlin, Germany.
(e) Emergency Department, Letterkenny University Hospital, Donegal, Ireland.
(f) Western Health and Social Care Trust, C-TRIC, Ulster University, Northern Ireland, UK.

Presentation Date and Time: Wed Apr 28 12:00:00 UTC 2021

Background: ECG data quality can be affected by lead misplacement which can affect clinical decisions. V1 and V2 are commonly misplaced in the superior direction from their correct position, which can mimic or conceal abnormalities. The aim of the current study is to use artificial intelligence (AI) in the form of deep learning to detect V1 and V2 lead misplacement to enhance ECG data quality and to make the black box decisions of AI systems more transparent by providing AI attention maps.

Methods: V1 and V2 signals were collected from 453 patients (normal n=151, Left Ventricular Hypertrophy (LVH) n=151, Myocardial Infarction n=151) and extracted using a high-resolution body surface potential maps (BSPM) and converted into RGB images. A deep convolutional neural network (CNN) with 68 layers was developed and trained to classify the ECG images of V1 and V2 into correct and incorrect placement. An attention map was generated and analysed for each ECG image in the last convolution layer to show the most important features (see figure 1) that have been selected by the CNN. CNN has been trained on 67% of the data and tested on 33%.

Results: Using CNN with 68 layers, the accuracy of detecting lead misplacement was 92.6% (TN=291/300, TP=265/300, FP=9/300, FN=35/300). Based on attention maps, P waves (56%), T waves (55%) and R (48%) waves contributed the most to the predicted classes correct and incorrect (see table 1). The S wave was not considered important in most cases in detecting correct V1 and V2 placement. The other features, including the PR interval, Q wave and J point contributed 29%, 17% and 27% respectively to the predicted classes correct and incorrect.
**Conclusions:** Deep CNN achieved a high accuracy (92.6%) to detect V1 and V2 lead misplacement, whilst increasing the transparency of the algorithmic decision making. Attention maps demonstrate what the algorithm 'looked at' prior to making it's decision, which also elucidate areas of the ECG that are most important in detecting lead misplacement. Physicians can use the attention map to calibrate their trust with the machine and to consider the machine's attention (a proxy for machine rationale). According to the generated attention maps, the P waves, T waves and R waves were considered the most important features, while the S wave was considered as the least important feature. Whilst the other features PR interval, Q wave and J point are considered as mid-level features.
Pediatric Heart Rate Variability Preceding In-Hospital Cardiac/Pulmonary Arrest

**Author(s):** Yu-He Zhang, PhD(a), Eric D. Helfenbein, MS(a), Saeed Babaeizadeh, PhD(a), Jeffery Chan, BA(b), Lynda J. Knight, MSN, BSN, RN, CPN(b), Felice Su, MD(c)

(a) Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA
(b) Revive Initiative for Resuscitation Excellence at Stanford Children’s Health, Palo Alto, CA, USA
(c) Stanford University School of Medicine, Palo Alto, CA, USA

**Presentation Date and Time:** Wed Apr 28 12:00:00 UTC 2021

**Background:** In-hospital cardiac/pulmonary arrest (CPA) can lead to death if not treated immediately and contributes to poor outcomes even after successful resuscitation. Predictive indications for CPA could identify patients at risk and allow early intervention. A reduction in heart rate variability (HRV) often occurs prior to adult cardiac arrest and sepsis in preterm infants. Studying pediatric HRV changes immediately preceding in-hospital CPA has the potential to enhance risk stratification.

**Methods:** Continuous pediatric patient-monitoring data was acquired using Philips Data Warehouse Connect, and included waveforms, beat-classifications, and R-R intervals measured by the arrhythmia algorithm with 0.5 msec resolution using parabolic ECG interpolation. Record length varied between a few and 24 hours. An initial database for preliminary study included 23 patient records with CPA and 23 without CPA as reference. The PhysioNet Cardiovascular Signal Toolbox provided HRV time-domain (TD) and frequency-domain (FD) calculations using 5-minute windows stepped 30-seconds. The Lomb-Scargle Periodogram was used for FD. HRV statistic trend graphs and histograms were visually compared between CPA and reference patients. The quantitative comparison between groups used 60-minute mean HRV statistics up to 5-minutes before CPA and randomly chosen for the reference group.

**Results:** The TD and FD HRV statistics providing predominant indications of lower HRV for CPA patients are shown in the table with p-values. A decrease in the HRV statistic trends before CPA was observed in some cases. Drastic increases in HRV (not included in statistics) were observed immediately (< 5 minutes) before CPA events but were mostly related to sudden bradycardias, ectopic beat interruptions, or other irregular rhythms.

**Conclusions:** In our preliminary database, a significant difference with lower HRV was observed between in-hospital pediatric patients with impending CPA events compared to a reference set. In addition, a temporal reduction of HRV was observed in some cases prior to CPA events but requires further study and characterization. HRV measures NNiqr, SDNN, FD
stats, and SD2 showed the predominant lower values for CPA patients while RMSSD and SD1 showed moderate differences. Larger databases allowing patient age, diagnosis, surgical, pharmacological, and sleep-state matching need to be developed and acute events separated from declining multi-organ failure CPA. HRV measurements may ultimately prove to be one significant input to complex multi-parameter predictive models for pediatric in-hospital CPA.
Deep Learning Neural Network can measure ECG intervals and amplitudes accurately

**Author(s):** Jorgen K. Kanters (a), Steven A. Hicks (b), Jonas L. Isaksen (a), Niels Grarup (a), Niels-Henrik Holstein Rathlou (c), Jonas Ghouse (a), Gustav Ahlberg (a), Morten Salling Olesen (a), Allan Linneberg (a), Christina Ellervik (d), Torben Hansen (a), Claus Graff (e), Paal Halvorsen (b), Michael Riegler (b).

(a) University of Copenhagen, Denmark  
(b) Simula, Oslo, Norway  
(c) Novo Nordisk Foundation, Hellerup, Denmark  
(d) Harvard Medical School, Boston, USA  
(e) Aalborg University, Denmark

**Presentation Date and Time:** Wed Apr 28 12:00:00 UTC 2021

**Background:** The aim of this study was to develop a deep neural network that can be used to reliably measure electrocardiograms (ECG) both in the voltage (amplitudes) and time (intervals) domain.

**Methods:** We used three parallel residual convoluted networks concatenated to a fully connected network with two layers, using the raw ECG waveforms as input (either 10 sec ECG (5000 samples*8 leads) or 1.2 sec median beat (600 samples*8 leads). For training (80% of GESUS ECGs) and validation (20% of GESUS ECGs), we used the GESUS population study with ECGs from 8,944 subjects to be trained with the GE 12SL parameters (intervals and amplitudes). The findings were replicated in the Inter99 population study consisting of 6,783 subjects using the weights from the GESUS trained neural network applied on the Inter99 ECGs and compared with the 12 SL values.

**Results:** As seen in the table, both intervals and amplitudes could be measured accurately by the neural network close to the sampling rate and the voltage resolution.

**Conclusions:** We found that our deep network performed very well in predicting amplitudes and intervals. Median ECGs were slightly easier to predict except for heart rate.
The Importance of Residual PVC Offset Correction for Inverse Localization of PVC Origin Using a Single Dipole

Author(s): Jana Svehlikova, PhD (a), Jan Zelinka, MS (a), Miroslav Haska, MS (a), Beata Ondrusova, MS (a), Katarina Kromkova, MS (b), Peter Hlivak MD, PhD (b), Robert Hatala, MD, PhD (b), Milan Tysler, PhD (a)

(a) Dept. of Biomeasurements, Institute of Measurement Science, SAS, Bratislava, Slovakia
(b) Dept. of Arrhythmias and Cardiostimulation, National Institute for Cardiovascular Diseases, Bratislava, Slovakia

Presentation Date and Time: Wed Apr 28 12:00:00 UTC 2021

Background: The influence of the ECG signal preprocessing on the results of various inverse solutions was recently studied on porcine signals recorded during ventricular pacing. For the inverse solution with a single dipole, it was shown that the accuracy of pacing electrode localization was strongly affected by subtraction of the residual pacing signal offset remaining after standard signal processing. Now, the impact of premature ventricular contraction (PVC) offset subtraction was studied on signals recorded from patients.

Methods: Body surface potentials from 128 electrodes on the torso were recorded for 5 to 20 minutes in 15 patients with spontaneous PVC. The baseline drift was removed using the cubic spline fitting of zero points defined before the P wave of the sinus beats. The signals from all heart cycles were then clustered according to their morphology. Signals from all clusters were averaged to reduce the high-frequency noise. At the end of the above described standard processing a remaining offset at the beginning of the averaged PVC cycle was observed (PVC offset). To localize the PVC origin, the inverse solution with a single dipole was computed with two different sets of input data. The first set consisted of the PVC beats obtained by standard processing, in the second set for each PVC beat signal the corresponding PVC offset was subtracted. The inverse solution was computed assuming both, homogeneous and inhomogeneous patient-specific torso model obtained by CT scan. The differences between the results obtained with and without additional PVC offset subtraction were evaluated.

Results: The number of heart cycles in the PVC clusters varied from 1 to 629. The mean PVC offset computed from 128 electrodes for each patient was 25±19 µV (from 4 to 87 µV). The distances between the inverse solutions obtained with and without the PVC offset correction were 18.8±15.6mm (0-64 mm) and 24.4±20.9 mm (4-86 mm) for the homogeneous and inhomogeneous torso model respectively. Only a weak correlation between the mean PVC offset for each patient, and the distance between their inverse solutions was observed (44% or 23%), i.e. the distance between the solutions obtained with and without the PVC offset correction did not depend on the PVC offset magnitude.
**Conclusions:** The inverse localization with a single dipole uses the very early time interval of the PVC activation. It was shown that even small PVC offsets can significantly influence the inverse solution. Therefore, the signals preprocessing should be carefully performed concerning the used inverse method.
Big data and the P-wave

Author(s): Claus Graff

Presentation Date and Time: Thu Apr 29 08:00:00 UTC 2021

Background: Using two large Danish cohorts with ECG recordings and cardiac CT scans linked to health registries we sought to investigate the relationship between electrocardiographic P-wave markers and morbidity and mortality.

Methods: In the greater region of Copenhagen, Denmark, most general practitioners referred their patients to one core facility (CGPL; Copenhagen General Practitioners' Laboratory) for ECG recordings between 2001 and 2015. We used 980,000 ECGs recorded from 480,000 individuals in this population. Additionally, we used 6,500 ECG and cardiac CT scans from a general population study. All ECGs were linked to the Danish Health Registries with diagnoses, hospital visits, prescriptions, and cause of death. A baseline ECG free of the endpoint studied was used to assess the risk of incident atrial fibrillation, stroke, heart failure, pacemaker implantation, and death on a population level and for the individual person. We used ECGs and cardiac CT scans to investigate the relationship between P-wave markers and left atrial size.

Results: Three P-wave markers: the duration of the P-wave, P-terminal Force V1 and Interatrial Block are robust predictors of atrial fibrillation, stroke, heart failure, pacemaker implantation, and death. Interatrial Block can be used to estimate risk of endpoints in the individual patient. The relationship between left atrial size by CT and ECG was poor.

Conclusions: The duration and morphology of the P-wave are robust markers of morbidity and mortality, even on an individual level. The P-wave appears to have limited value in estimation of left atrial dilation.
Spectral characterization of the atrial activity in the surface ECG has been proposed as a means to quantify both the disease state and the response to treatment in patients with atrial fibrillation (AF). The most well-known spectral measure is the atrial fibrillatory rate (AFR), also known as dominant atrial frequency, used to describe the complexity of the AF signal in numerous studies. Calculation of the AFR is based spectral analysis or time-frequency analysis of the residual ECG once the QRS complexes and T-waves have been cancelled. AFR was initially introduced as the dominant frequency in the spectrum of the AF signal but was later robustly computed as the average frequency of a frequency trend produced by time-frequency analysis. AFR has been proposed as an index of atrial organisation. Clinically, AFR has been investigated for prediction of intervention effects as well as for monitoring of drug effects. While AFR has been shown to be useful for monitoring of drug effects, prediction of intervention effects have so far been less conclusive due that patients with the same AFR may differ in many other respects.

Waveform analysis is a more recent approach which is based on time-frequency analysis and make use of harmonic amplitudes and phases in the atrial signal spectrum. Harmonic phases are sensitive to noise and cannot be averaged and must therefore be calculated blockwise for very short signal blocks and clustered into the most representative waveforms of the signal. Waveform analysis provides a means to identify patients with different f-wave morphology, but is also useful for quality control and AF detection to confirm the presence of f-waves.

In this work, different types of spectral measures are reviewed in relation to outcome prediction, drug response analysis, understanding of mechanisms, quality control, and AF detection. The clinical significance of the methods as well as their limitations and associated challenges are described. The use of spectral characterization is discussed in terms of how it may be combined with new analysis methods and other patient-specific information.
In 2009, SCHILLER AG released a so-called AF Toolbox as an option for one of its high-end ECG devices. This AF Toolbox was built around an algorithm that separates the atrial from the ventricular signals in a standard 12 lead ECG and not only presents the separated signals, but also some additional parameters like the atrial rate or the direction of rotation of atrial flutter waves. While the clinical interest in this tool was very limited, the underlying separation algorithm still allows for working on interesting questions.

The Swiss-AF study was initiated by the University Hospital Basel in 2014 and includes subjects with documented AF across 13 sites in Switzerland. Among other variables, the Swiss AF study collects yearly ECGs from the included subjects.

In this work, we apply the AF Toolbox’ separation algorithm to ECGs that were collected as part of the Swiss-AF study and train a convolutional neural network to estimate which of two ECGs from the same subject is older solely based on the atrial signal.

Based on 2158 patients with at least two ECGs, a simple convolutional neural network achieved the following accuracies:

- 1 year difference between the ECGs: 55%
- 2 years difference between the ECGs: 61%
- 3 years difference between the ECGs: 68%
- 4 years difference between the ECGs: 73%

Unsurprisingly, the performance increases with the time between the recordings.
Invasive and Non-Invasive Substrate Characterization of AF

Author(s): Uli Schotten

Presentation Date and Time: Thu Apr 29 09:40:00 UTC 2021

Quantification of the frequency and complexity dynamics of atrial fibrillation (AF) by advanced analysis of surface ECGs appears to be a logical step towards non-invasive quantification of the individual degree of electro-pathological alterations in the atria. Numerous studies have addressed the correlation between non-invasive and invasive electrophysiological properties of the atria in patients with AF e.g. a correlation between dominant frequency sites on the torso with dominant frequency in the nearest part of the atrium. More recently, it was demonstrated that AF complexity defined as number of stable re-entry sites were concordant between non-invasive and invasive recording techniques. Also the predictive value of ECG markers for AF frequency or complexity has been demonstrated in various clinical settings. Which markers is most predictive in which clinical setting still has to be addressed in larger clinical trials.

Research on repetitive conduction patterns during AF has recently attracted attention as they may reflect anatomical structures harbouring preferential conduction paths and indicate the presence of stationary sources for AF. Recently, we demonstrated a novel technique to detect repetitive patterns in high-density contact mapping of AF. As a first step towards repetitive pattern mapping to guide AF ablation, we determined the incidence, prevalence, and trajectories of repetitive conduction patterns in epicardial contact mapping of paroxysmal and persistent AF patients. In persistent AF patients, repetitive patterns were less frequent, smaller, and more variable than in paroxysmal AF patients. Future research should elucidate whether these patterns can help in finding AF ablation targets.
Prehospital ST-depression and T-wave Inversion are Associated with New Onset Heart Failure in Individuals Transported by Ambulance for Suspected Acute Coronary Syndrome

Author(s):

Presentation Date and Time: Thu Apr 29 10:20:00 UTC 2021

Background:

Methods:

Results:

Conclusions:
Identification of ion channel blocks by continuous T vector velocity effect profiles in CiPA studies

Author(s):

Presentation Date and Time: Thu Apr 29 10:50:00 UTC 2021

Background:

Methods:

Results:

Conclusions:
RightQT: Accurate QT correction method based on the exact dynamical dependence between RR and QT intervals

Author(s):

**Presentation Date and Time:** Thu Apr 29 11:20:00 UTC 2021

**Background:**

**Methods:**

**Results:**

**Conclusions:**
Background: Ablation has become a widespread treatment option for patients with Atrial Fibrillation (AF). However, a significant number of patients show recurrence within 12 months. This study aims to compare patients with and without post ablation recurrence, determining the best features extracted from RR intervals of the 500 beats preceding the patient's most recent AF episode as well as some clinical features.

Methods: The RR intervals from 92 AF patients (56.3±10.9 years, M 72%) before ablation were extracted from and recorded by an Insertable Cardiac Monitor (ICM) system. Classical Heart Rate Variability (HRV) features were then computed including Mean, pNN50, pNN20, RMSSD, SDNN, TINN, TRI, Approximate and Sample Entropy, SD1, SD2 and SD1SD2 ratio, and Detrended Fluctuation Analysis, Alpha1 and Alpha2. Potentially clinically relevant parameters such as AF type (Paroxysmal or Persistent) and lesion type (PVI only or PVI plus extra lesions) were also extracted. Two classes of patients, those with Recurrence, defined as existence of a recorded AF episode after a 3 months blanking period, and those with No Recurrence, were compared (Student's t-test for the numerical features and Pearson's chi-squared test for the categorical features).

Results: Out of the 92 patients that underwent the ablation, 43 (47%) were classed as No Recurrence and 49 (53%) as Recurrence. The extracted numerical features that were significantly different between the 2 groups (p-value < 0.05) were pNN50 and pNN20. For the categorical features, the study highlights that PVI plus extra lesions lead to 60% of Recurrences. In addition, patients with Persistent AF had higher Recurrence (68%) than patients with Paroxysmal AF (49%). The chi-square test showed no significant differences for the categorical features.

Conclusions: Classical HRV features: pNN50 and pNN20, proved to be valuable features to be considered. The results concerning the patients with extra lesions lead us to the hypothesis that extra damage resulting on a stiffer left atrium with more scar tissue could favor the AF sustenance mechanisms, therefore increasing the chance of Recurrence. However, further analysis should be made as the test yielded a non-significant difference possibly due to having a small patient population (23 patients).
A New Graphical Method for Reporting Performance Results of Diagnostic Tests

Author(s): John Wang, MS

Philips Healthcare, Andover, MA, USA

Presentation Date and Time: Thu Apr 29 12:10:00 UTC 2021

Background: As a standard practice for decades, numerous performance measures, such as sensitivity, specificity, positive/negative predictive values, and positive/negative likelihood ratios, have been defined and used for reporting the performance results of diagnostic tests. Issues with current reporting practice using these standard performance measures include: 1) difficult to get a complete picture of the diagnostic performance since only a subset of all performance measures are typically reported, 2) difficult to visualize the complex relationships of the performance measures since only numerical results are reported, and 3) difficult to teach/learn and memorize the large number of performance measures and their relationships. To overcome these shortcomings, a new graphical performance presentation has been developed to improve the reporting and understanding of the diagnostic test results.

Methods: A two-dimensional graph is constructed with sensitivity as the left-axis, specificity as the right axis, and prevalence as the horizontal axis. Three straight lines (a vertical prevalence-line, a horizontal sensitivity-line, and a horizontal specificity-line) are plotted to form four areas representing the normalized values of true-positive, false-negative, false-positive, and true-negative, respectively. Other performance measures are represented as line segment (e.g., sensitivity, specificity, and prevalence), ratio of line segments (e.g., positive and negative likelihood ratios), ratio of areas (e.g., positive and negative predictive values), and sum of areas (e.g., overall accuracy).

Results: With the proposed graphical presentation, it is shown that a total of 19 commonly used diagnostic performance measures can be presented simultaneously and visualized in a single two-dimensional graph. To demonstrate the value of this new graphic method, several examples are provided: 1) relationship between prevalence and algorithm performance specified by sensitivity and specificity, 2) dependency of prevalence and the single-valued overall accuracy performance measure and the well-known accuracy paradox problem, 3) trade-off of sensitivity and specificity in algorithm design for improving predictive values.

Conclusions: A new graphic presentation has been developed for performance reporting with several major advantages: 1) large number of performance measures can be presented and visualized simultaneously in a single graph, 2) complex relationships of all performance measures can be understood more easily, 3) a great teaching tool in explaining the relationships of the commonly used performance measures, and 4) the graph reduces the need to memorize
some of the complex formulas for performance measures. Because of these advantages, the performance graph should be considered as a standard for performance reporting so that reporting can be standardized and meaningful performance comparison can be performed.
Annotation Protocol Designed to Improve Ventricular Tachycardia Identification during In-Hospital ECG

**Author(s):** Michele M. Pelter, RN, PhD (1), Mary G. Carey, RN, PhD,(2) Salah Al-Zaiti, RN, PhD,(3) Jessica Zegre-Hemsey,(4) Claire Sommargren, RN, PhD,(1b) David Mortara,(1c) PhD, Fabio Badilin, PhD,(1d)

(1) University of California, San Francisco (UCSF), School of Nursing
(2) Associate Professor, Director of Clinical Nursing Research Center, University of Rochester, School of Nursing
(3) Associate Professor of Nursing & Emergency Medicine University of Pittsburgh School of Nursing
(4) UNC Chapel Hill School of Nursing
(a) Assistant Professor, Director, ECG Monitoring Research Lab, Associate Translational Scientist, Center for Physiologic Research
(b) Assistant Professor
(c) Associate Professor, Founder, Center for Physiologic Research
(d) Director, Center for Physiologic Research

**Presentation Date and Time:** Thu Apr 29 12:10:00 UTC 2021

**Background:** Background: One goal of continuous electrocardiographic (ECG) monitoring in the hospital setting is to identify lethal arrhythmias. While audible alarms are used to alert busy clinicians, our team found that 90% of all audible arrhythmia alarms were false, with ventricular tachycardia (VT) being particularly problematic. Nurses eventually become desensitized to alarm noise, now known as alarm fatigue, and inadvertently ignore and/or respond with unsafe practices (i.e., adjust volume down/off). Providers are also impacted because they are contacted when alarms occur and must interpret them as true or false and then decide if an intervention(s) is indicated. Interventions tested to date suggest that alarm fatigue can be solved by nurses (i.e., skin electrode preparation/changes, adjust alarm parameters, and/or education). While these strategies have had some impact on reducing alarms, these interventions have not addressed the central problem, false alarms due to poorly designed ECG algorithms.

**Methods:** Methods: The purpose of this project is to describe an ongoing effort which aims to establish a very large database of carefully annotated VT alarms using de-identified ECG data collected from 77 ICU monitors. The ICU types include; cardiac (16 beds), medical/surgical (32 beds), and neurologic (29 beds. The VT alarms have been identified using an algorithm developed by our team of engineers. Each VT alarm generated, will then be annotated as true or false by a team of five Nurse Scientists, all PhD prepared, from four US based Schools of Nursing. VT alarms will be randomly assigned to three of the annotators using a secured web-based platform that displays all seven ECG leads, as well as physiologic waveforms if available (i.e., arterial blood pressure, Sp02). Disagreements are automatically re-assigned to
another annotator or, in the instance of further disagreement, to a panel of cardiologists and engineers for final reconciliation.

**Results:** Results: The 20-month dataset generated over 20,000 VT alarms. In our presentation, we will provide the following: details of the annotation protocol; VT operational definitions; and illustrate the web-based annotation tool. In addition, inter-rater reliability estimates, the frequency of disagreements and reasons for disagreements.

**Conclusions:** Conclusions: The ultimate goal of this annotation effort, in collaboration with regulatory agencies, is to establish the single largest VT database available to test and improve the accuracy of ECG algorithms; thus, reducing alarm fatigue among clinicians.
Continues Live Measurement of Heart Rate and RR Intervals Using the new Integrated Features of the Chromium Internet Browser Family

Author(s): Thomas Hilbel (1,3), Wolfram Stein (1), Gwendolyn Mayer (2), Jobst-Hendrik Schultz (2), Hugo A Katus (1)

(1) Dept. of Cardiology, University Hospital, Heidelberg, Germany
(2) Psychosomatic and General Medicine, University Hospital, Heidelberg, Germany
(3) University of Applied Sciences, Gelsenkirchen, Germany

Presentation Date and Time: Thu Apr 29 12:10:00 UTC 2021

Background: Bluetooth Devices for Health, Fitness or Wellness are being used more and more frequently. However, in order to display and to transfer the data of the devices, it was always necessary to install special computer programs on PC’s or dedicated apps on mobile devices. Recently, however, Chromium developers have implemented a new functionality in the browser that allows the browser to directly read, display and analyze data from Bluetooth Low Energy (BLE) devices.

Methods: With JavaScript (JS), the computer language for the web, two web browser based heart rate measurement program demonstrators were written. JS is a language whose code can be interpreted by web browsers. As a heart rate sensor we used the Polar H7 & H10 with a RR-Interval measurement resolution of 1024Hz. To communicate securely from within the web browser with a BLE heart rate sensor we used the Web Bluetooth work-in-progress API (WBT_API) and JS. The WBT_API allows access to information from GATT BLE devices like heart rate sensors, health thermometer, glucose sensors, SpO2 sensors etc.

Results: The two demonstrator programs are able to connect to standard wireless BLE heart rate monitors from any PC, Tablet or mobile phone, that can run a Chromium browser like Google Chrome, the new Microsoft Edge or the Chromium open source browser. One program does display the average heart rate, the RR-intervals and HRV Parameters within the browser. The second program does estimate the breathing rate from the sensors RR-intervals to perform a biofeedback exercise. All heart rate values transferred by the sensor to the browser can also be saved for later analysis. The two programs can be run on either the server or the client.

Conclusions: While previously wireless sensor recording always required the installation of a proprietary app, with the Web Bluetooth API vital signs for health, sports and wellness can be wireless recorded, displayed and processed independent of the type of device or the operating system in a web browser. The developer can write one program and the same program will work on different operating systems. And the user only needs to open the browser to collect data. Through the BLE GATT protocol a lot of health sensors can be connected, and the new WEB API makes it easier to capture wireless sensor data for research and patient care scenarios.
Mutations in the genes encoding cardiac ion channels may contribute in life-threatening arrhythmias in patients with hypertrophic cardiomyopathy

Author(s): E. Zaklyazminskaya, MD, PhD, (a), N. Chakova, BSc, PhD, (b), S. Komissarova, MD, PhD, (c), S. Niyazova, BSc, (b), A. Shestak, BSc, (a), S. Dzemeshkevich, MD, PhD, (a)

(a) - Petrovsky National Research Centre of Surgery, Moscow, Russia
(b) - State scientific institution, The Institute of Genetics and Cytology of the National Academy of Sciences of Belarus, Minsk, Republic of Belarus
(c) - State Institution Republican Scientific and Practical Centre Cardiology, Minsk, Republic of Belarus

Presentation Date and Time: Thu Apr 29 12:10:00 UTC 2021

Background: Hypertrophic cardiomyopathy (HCM) is the most common inherited cardiomyopathy with estimated prevalence 1:200 across all ethnic groups. Rare/unique mutations in the genes encoding sarcomeric proteins are primary causative factors but other genetic and environmental impacts may influence significantly disease course even within one family. Nonsustained ventricular tachycardia is a major risk factor for sudden cardiac death (SCD), a common outcome of HCM but the underlying mechanism of ventricular arrhythmias in HCM is largely unknown. Family history of SCD is considered as a major risk factor for HCM patients but the correlation between particular mutation(s) and risk of arrhythmias is not proven yet.

Methods: Genetic study was performed on DNA samples from 80 unrelated patients diagnosed with HCM based on current diagnostic criteria (ESC 2014). Seventy-nine patients had HCM and 5-year risk of SCD>6%, and 1 autopsy sample was taken from an SCD victim (male, 20 y.o.) with HCM revealed post-mortem. Genotyping was performed using the TruSight Cardio Sequencing Kit (Illumina) or Whole Exome Sequencing (NextSeq, Illumina).

Results: Rare genetic variants in the genes encoding cardiac ion channels were detected in 16 out of 80 HCM probands (20%). Six variants were pathogenic (Class V) and 2 variants likely pathogenic (Class IV). Nine substitutions were classified as Class III variants (variants of unknown significance) but they had a high score of potential influence on protein function according to in silico prediction tools. Distribution of the variants was as follows: 4 variants in the KCNQ1 gene, 3 variants in the KCNH2 gene, 3 variants in the SCN5A gene, 4 variants in the CACNA1C gene, and 2 variants in the ANK2 gene. Classic sarcomeric mutations were revealed only in 8 out of these 16 patients. Carrying two genetic hits was previously considered as an independent risk factor for SCD and rapid disease progression by many authors.
**Conclusions:** Carrying of significant genetic variants in the genes encoding cardiac ion channels is not so rare (up to 20%) in high-risk subgroup of HCM patients. It might be an independent genetic factor contributing to arrhythmogenesis in HCM patients regardless of presence of the mutation in the genes encoding sarcomeric proteins. Whole exome sequencing (WES) might be a preferable testing method for HCM patients with high risk of SCD.
Record Segmentation to Speed Up Long-Term ECG Analysis Algorithms

Author(s): Ben Bailey, Saeed Babaeizadeh Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA

Presentation Date and Time: Thu Apr 29 12:10:00 UTC 2021

**Background:** Increased ECG record lengths (> 14 days) and CPU intensive additions (e.g. p-wave analysis) increase the processing time of legacy long-term off-line ECG analysis algorithms. This decreases the daily count in processing centers, increases the record edit time, and reduces the usability of the analysis application. Legacy algorithms, developed several years ago mainly for analyzing 24-hour Holter recordings, use single thread processing. Most compilers limit single thread software to a single core. Therefore, even though most modern computers contain multiple-core CPUs, these algorithms are unable to utilize the advanced hardware. Restructuring these algorithms to a multi-threaded architecture is complex work and may need extensive reliability testing. We propose the much simpler ECG record segmentation as an alternative to algorithm restructuring.

**Methods:** First, we divide the ECG record into multiple segments with a length dependent on the number of available CPU cores. Then we process all the segments simultaneously using the existing algorithm; one CPU core for each segment. Finally, we combine the resulting segmented annotations. This way, the legacy algorithm is not modified, and the improvement is achieved through pre-processing of the data and post-processing of the algorithm output.

**Results:** To test the impact of our technique on the speed and accuracy of beat detection, we broke 95 48-hour 3-channel Holter ECG records into 6, 8, 12, and 24-hour segments. Using an in-house variant of the Philips CalgTM arrhythmia algorithm on a PC with an 8-core CPU, we compared beat detections for the contiguous 48-hour record to those for segmented ECGs. We used paired timestamps to measure processing time and Physionet BxB to quantify beat detection match, as summarized in the table below. The segmentation method significantly accelerated the algorithm without much impact on beat detections. The main source of difference in beat detections was the algorithm behavior in extreme noise. Specifically, the algorithm behaves differently if it has to start learning the beat templates in a noisy segment or if it enters noise in the middle of processing and then recovers when the noise clears.

**Conclusions:** It is possible to significantly speed up legacy off-line long-term ECG algorithms without modifying the algorithm code itself. This way such algorithms that have been thoroughly tested in the market for several years can be utilized to efficiently process very long ECG recordings.
Regression or pseudo-inverse - which method should be preferred when developing inverse linear ECG-lead transformations?

Author(s): Daniel Guldenring, MEng, PhD (a), Ali Rababah, MSc (b), Dewar D. Finlay, BSc, PhD (b), Raymond R. Bond, BSc, PhD (b), Alan Kennedy, BSc, PhD (b), James McLaughlin, PhD (b)

(a) HTW Berlin, Berlin, Germany
(b) Ulster University, Belfast, United Kingdom

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Background: Linear electrocardiogram (ECG) lead transformations are a well-established concept in modern computerized electrocardiography. Linear ECG-lead transformations estimate or derive unrecorded target leads by applying a number of recorded basis leads to a so-called linear ECG-lead transformation matrix. The inverse transform of such a linear ECG-lead transformation performs a transformation in the opposite direction (from the target leads to the basis leads). The pseudo-inverse of a given transformation matrix can be used to perform such an inverse transformation. Linear regression based inverse transformation matrices are, provided that sufficient training data for their development is available, an alternative to pseudo-inverse matrices. The aim of this research was to compare the estimation performance of pseudo-inverse and linear regression based inverse transformations. This comparison was performed for two example linear ECG-lead transformations.

Methods: First, standard 12-lead ECGs and Frank vectorcardiograms (VCGs) were extracted from body surface potential maps (BSPMs) of n=726 subjects (left ventricular hypertrophy, n=232; old myocardial infarction, n=265; normal subjects, n=229). Second, the dataset was randomly divided into one training dataset (DTrain, n=545) and one testing dataset (DTest, n=181). Third, linear regression and the data in DTrain were used to generate two linear ECG-lead transformation matrices (one for the transformation of the 12-lead ECG to the Frank VCG and one for the opposite direction). Forth, the pseudo-inverse for each of the two transformation matrices was computed. Fifth, the four matrices and the data in DTest were used for the estimation of the Frank VCG and the 12-lead ECG. Sixth, root-mean-squared-error (RMSE) values between the QRS-T complexes of recorded and derived leads were determined. Seventh, the mean and the 95% confidence interval of the RMSE values were calculated for each of the derived leads.

Results: Table 1. Root-mean-squared-error (RMSE) values calculated between the recorded and derived leads. The mean (95% confidence interval) of the RMSE values were computed using the data of the 181 subjects in DTest.

Conclusions: The findings in Table 1 suggest that pseudo-inverse based inverse ECG-lead
transformation matrices perform less favorable when compared to their regression-based alternatives. Provided that sufficient training data are available, linear regression should be used for the development of inverse ECG-lead transformation matrices.
ECG Reading Differences Demonstrated on Two Databases

**Author(s):** Richard E. Gregg MS (a), Ting Yang PhD (a), Stephen W. Smith, MD (b), Saeed Babaeizadeh PhD (a)

(a) Advanced Algorithm Research Center, Philips Healthcare, Andover, MA USA  
(b) Hennepin County Medical Center, Minneapolis, MN, USA

**Presentation Date and Time:** Thu Apr 29 12:10:00 UTC 2021

**Background:** Most studies that rely on ECG reading as a reference use multiple ECG readers and a method to resolve differences. Readers often use different criteria. The aim of this study is to show the effect of differences in ECG reading style on training automated ECG interpretation.

**Methods:** An algorithm based on interpretation from similar ECGs was tested on two databases, one from Minnesota (MN) and one from China (CN). MN consisted of 146,000 ECGs collected at a single hospital. CN consisted of 194,000 ECGs from multiple hospitals. Each database was randomly split into DB (80%) and query (20%) subsets. Interpretation for each query set was generated from weighted average voting on similar ECGs from the particular DB. Four sets of results were generated, two within-database and two cross-database results. Comparison was based on the F1 score, harmonic mean of sensitivity (SE) and positive predictive value (PPV), algorithm versus reference annotation. PPV was estimated from sensitivity, specificity and prevalence to reduce the impact of differing prevalence between databases. Quality of nearest neighbor query was measured by mean K-d tree distance.

**Results:** [Table] F1 scores were higher when the query and DB subsets were from the same database. F1 scores were high for the bundle branch block categories no matter the database combination, suggesting that bundle branch blocks are read in the same way. The drop in F1 score from within-database to cross-database for other categories was not due to a drop in either SE or PPV alone but both simultaneously. Mean K-d tree distance was double (worse) for cross-database nearest neighbor search.

**Conclusions:** For most categories, expert readers appear to have used different criteria for ECG interpretation, as evident by the big difference between cross-database and within-database performance. Bundle branch blocks seem to be the only exception, interpreted in a consistent manner.
A Full-Automatic Software Program for Analyzing ECG in Holter Applications

Author(s): Antoun Khawaja, PhD

Khawaja Medical Technology GmbH, Munich, Germany

Presentation Date and Time: Thu Apr 29 12:10:00 UTC 2021

Background: Reliable ECG Rhythm analysis and detection of serious cardiac trends are essential for the recognition of cardiac rhythm diseases and also for providing quick treatment. This will improve cardiac safety in many ECG applications including home-monitoring, ambulatory Holter, and cardiac drug safety.

Methods: The Holter ECG analysis program, presented in this work, provides localization, classification, and measurements for every single heartbeat with very high precision even in case of noisy ECG signals. Besides, numbers of basic and advanced cardiac rhythm analyses are performed by the program in order to detect numerous cardiac events including critical ventricular and atrial arrhythmia. Furthermore, various cardiac trends including PR interval, QT and QTc trendings are also provided. The program is designed not only to handle single-channel and multi-channel lead schemes but also to manage input ECG signals digitalized in different sample frequencies. Furthermore, it can be configured to meet the individual needs of users.

Results: The detection of the heartbeats is validated using MIT-BIH Arrhythmia Database, AHA Series1 and AHA Series 2. The sensitivity and specificity are both greater than 99.7 % in all databases. The classification of the heartbeats is also validated the same databases mentioned above. The sensitivity and specificity are greater than 93.5 % and 96.5 % in all databases, respectively. The delineation algorithm used by the program is validated and tested according to the procedure and databases described in the standard IEC 60601-2-25:2011. Several initial validations showed very promising results in detecting atrial fibrillation and ventricular fibrillation sofar. However, extensive validation processes are carried out at present for many critical cardiac events. Results are expected in the near future.

Conclusions: Due to its high accuracy, the program can be used to minimize the hazard and risk to patients and to increase the overall cardiac safety.
Electrocardiogram report system: the importance of decision-making tools

Author(s): Paulo R. Gomes, BSc (a), Gabriela M. Paix (a), MSc. MD (a), Emilly M Lima, MSc., Milena S. Marcolino, PhD MD(a), Leonardo B. Ribeiro BSc(a), Graziela Chequer, PhD MD(a), Maria B.M. Alkmim, MSc(a), Peter W. Macfarlane, PhD (b), Antonio L. Ribeiro, PhD(a)

(a) Telehealth Center, University Hospital and Medical School, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil
(b) Institute of Health and Wellbeing, University of Glasgow, Glasgow, Scotland

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Background: The electrocardiogram (ECG) is an easy-to-perform, non-invasive and low-cost exam, used from a primary care center to the intensive care unit. Reporting ECG findings can be an exhaustive task in cardiology services. There are several systems dedicated to the management of ECG exams, but few include decision-making tools to support the cardiologist. We aimed to develop a new ECG system designed to manage a large tele-ECG service, supporting the cardiologist to give an accurate report. This work was conducted at the Telehealth Center of the Hospital das Clínicas of the Federal University of Minas Gerais (CTS-HC-UFMG), which has performed more than 4.3 million ECGs since its implementation in 2006. The CTS-HC-UFMG maintains a 24-hour ECG online service that receives and reports an average of 3,000 exams per day performed in primary care centers and emergency units.

Methods: A new web-based ECG reporting system was developed, based both on user experience and logical diagnostic processes. The cardiologist analyzes the exam as a whole and identifies abnormal patterns that lead to a final diagnosis. He/she should choose the ECG diagnosis in a hierarchic list, based in AHA/ACC/HRS/ISCE standardization. Only ECG diagnosis compatible with the current information are available to be chosen, although the other diagnosis must meet prerequisites to include them. A detailed final report is generated automatically, based on a selected diagnostic, combining multiple statements. The system was extensively tested and refined until it was released in 2018 May. The telecardiology service is audited periodically by a senior cardiologist, who reviews a sample of the ECG those in disagreement with the gold standard evaluation are reviewed with the attending physician. The effectiveness of the new ECG system is evaluated by comparing the rate of disagreement before and after the implementation of the new system.

Results: More than 1,000,000 ECG have been analyzed after the implementation of the new system. All cardiologists evaluated positively. Dataset is composed of 4313 audits in the old system and 2213 in the new version. The disagreement rate fell from 14.7% (Q1-Q3: 11.0-17.3), in the period before the implementation (2015-2017) to 8.6% (7.2-9.5) after the implementation.
(2018-2019), p = 0.004.

**Conclusions:** A new web-based ECG reporting system was developed and successfully improved the accuracy of ECG reporting in a busy tele-ECG service. An user-friendly interface and the ability of mimicking the process used by the cardiologist to find a diagnosis are factors related to the success of this new ECG system.
mHealth and Arrhythmia Management: Perspectives from the 2021 ISHNE/HRS/EHRA/APHRS Collaborative Statement

Author(s): Niraj Varma

Presentation Date and Time: Fri Apr 30 08:00:00 UTC 2021

This session discusses points from the consensus statement from the International Society for Holter and Noninvasive Electrocardiology/ Heart Rhythm Society/ European Heart Rhythm Association/ Asia-Pacific Heart Rhythm Society which describes the current status of mobile health ("mHealth") technologies in arrhythmia management. The range of digital medical tools and heart rhythm disorders that they may be applied to and clinical decisions that may be enabled are discussed. The facilitation of comorbidity and lifestyle management (increasingly recognized to play a role in heart rhythm disorders) and patient self management are novel aspects of mHealth. The promises of predictive analytics but also operational challenges in embedding mHealth into routine clinical care are explored.
Wearables: European perspective (ESC WG e-Cardiology report)

Author(s): Magnus T. Jensen

Presentation Date and Time: Fri Apr 30 08:30:00 UTC 2021

Commercially available health technologies such as smartphones and smartwatches, activity trackers and sensors, commonly referred to as wearables, are increasingly available and used both in the leisure and healthcare sector. The widespread use of wearable technologies provide unparalleled opportunities for capturing physiological information from large populations in the community, which has previously only been available in patient populations in the setting of healthcare provision. The availability of low-cost and high-volume physiological data from the community also provides unique challenges. The aim of the talk is to discuss opportunities, specific barriers, and knowledge gaps in order to support the implementation of wearables into clinical cardiovascular medicine.
ISCE & Electrocardiography: Past, Present & Future

Author(s):

**Presentation Date and Time:** Fri Apr 30 09:10:00 UTC 2021

**Background:**

**Methods:**

**Results:**

**Conclusions:**
Novel Approaches to ECG Feature Selection for Dimensionality Reduction to Optimize ACS Detection using Only the Prehospital 10-second, 12-Lead ECG

Author(s): Zeineb Bouzid, BS;(a) Ziad Faramand, MD;(a,e) Christian Martin-Gill, MD;(c,e) Clifton Callaway, MD, PhD;(c,e) Samir Saba, MD;(d,e) Richard E Gregg, MS;m(f) Ervin Sejdic, PhD;(a) & Salah Al-Zaiti, RN, PhD (b,c,d)

(a) Department of Electrical & Computer Engineering;
(b) Department of Acute & Tertiary Care Nursing;
(c) Department of Emergency Medicine;
(d) and Division of Cardiology at University of Pittsburgh, PA, USA
(e) University of Pittsburgh Medical Center (UPMC), Pittsburgh PA, USA and
(f) Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA

Presentation Date and Time: Fri Apr 30 10:20:00 UTC 2021

Background: Novel temporal-spatial features of the 12-lead ECG can conceptually optimize ACS detection beyond that of classical ST amplitude measurements. However, identifying features that are mechanistically linked to ischemia and can serve as electrical biomarkers is challenging. We sought to develop a data-driven approach for ECG feature selection that combines machine learning techniques and clinical expertise to build a clinically-relevant algorithm for real-time detection of ACS.

Methods: This was a prospective observational cohort study of chest pain patients transported by EMS to three tertiary care hospitals in the US. We obtained raw 10-sec, 12-lead ECGs (500 s/s, HeartStart MRx, Philips Healthcare) obtained in the field and followed patients up to adjudicate clinical outcomes. Using previously-validated manufacturer-specific software, a total of 557 global and lead-specific features of P-QRS-T waveform were harvested from the representative average beats (subintervals, amplitudes, areas, axes, angles, loops, and eigenvalues). The number of features was reduced using two different approaches. First, an experienced clinician reviewed all available ECG features and identified 66/557 metrics that are mechanistically linked to myocardial ischemia. Second, after eliminating highly correlated features using Pearson correlation heatmaps, we ran Cohen’s d effect size, t-test, Recursive Feature Elimination and LASSO to identify 39/557 most recurrent and important features. We then built a machine learning-based logistic regression classifier to predict ACS using all extracted features (LR557); the manually selected features (LR66); and the recurrent data-driven features (LR39). Classifiers were evaluated using 10-fold cross-validation with 70%-30% training-testing sets for each fold then compared to the performance of a rule-based commercial proprietary software (STEMI10, Philips Healthcare).
Results: Our sample included 750 patients (mean age 59±17, 42% female, 15% confirmed ACS). The classification performance (AUC) of STEMI10, LR557, LR66, and LR39 classifiers were 0.63, 0.72±0.09, 0.75±0.08, and 0.81±0.07 respectively. Compared to STEMI10, LR39 classifier not only yielded 37% gain in sensitivity (0.713 vs. 0.339) but it also maintained a higher negative predictive value (0.931 vs. 0.884). The following data-driven features were both most important and physiologically plausible: Tpeak–Tend, non-dipolar components of ST segment and T wave, PCA ratio of STT waveform, axis of global T wave inflection point before Tpeak, T loop morphology dispersion, and global T wave asymmetry.

Conclusions: Our machine learning-based approach identified a subset of novel ECG features that not only improve ACS detection, but also provide important insights for developing cardiac electrical biomarkers that are mechanistically-linked and clinically relevant.
Electrocardiographic Differences in Acute Ischemic Responses to Exercise and Pharmacological Stress

Author(s): Brian Zenger (1,2,3,4), Jake A. Bergquist (1,2,3), Wilson W. Good (1,2,3), Lindsay Rupp (1,2,3), Rob S. MacLeod (1,2,3,4)

(1) Scientific Computing and Imaging Institute, University of Utah, SLC, UT, USA
(2) Cardiovascular Research and Training Institute, University of Utah, SLC, UT, USA
(3) Department of Biomedical Engineering, University of Utah, SLC, UT, USA
(4) School of Medicine, University of Utah, SLC, UT, USA

Presentation Date and Time: Fri Apr 30 10:50:00 UTC 2021

Background: Cardiac stress testing by exercise and pharmacological means is considered almost interchangeable but have never been carefully compared in a highly controlled setting. The choice of approach depends primarily on patient exercise capacity, and the results are considered equivalent. The goal of this study is to test in a highly instrumented animal model the hypothesis that exercise (mimicked by rapid cardiac pacing) and dobutamine infusion create identical ECG patterns and zones of intramyocardial ischemia from acute myocardial ischemia.

Methods: We used our unique experimental animal model of acute myocardial ischemia, which can simultaneously record electrical potentials within the myocardium, on the heart surface, and on the torso surface in high-resolution, while controlling ischemic load with variable left anterior descending coronary vessel occlusion and rapid atrial pacing or pharmacological stress. Pharmacological stress was induced using standard clinical dobutamine infusion protocols while BRUCE exercise protocols via electrical pacing mimicked exercise, under identical degrees of coronary occlusion. We determined the resulting ischemic zones from 200-280 intramyocardial and 247 epicardial electrograms and measured ECG markers from 96 torso surface electrodes. Torso and epicardial surface signals were compared using a matched t-test. Ischemic volumes within the myocardium were compared using a dice overlap coefficient.

Results: We compared ten pacing and ten dobutamine episodes across three porcine and two canine studies and for matched heart rates found significantly different ST40 values on both torso and epicardial surfaces (p<0.05 paired t-test). In addition, ischemic zones within the myocardium were significantly different (dice overlap coefficient <0.5).

Conclusions: In this preliminary analysis, we found that simulated exercise vs. pharmacological cardiac stress produced different ECG markers of ischemia on both torso and epicardial surfaces, which were the consequences of different ischemic zones located within the myocardium. These results suggest that different types of cardiac stress also differ in the extent and perhaps the nature of the resulting ischemia. Therefore, improved diagnostic performance from body surface ECGs could be possible with clinical metrics and thresholds that are adjusted to the type of ischemic stress. Future work will explore the trends seen in this initial analysis.
Electrocardiographic Imaging (ECGI) can Improve Endocardial Mapping for Wavefront Reconstruction and PVC Localization

Author(s): Wilson W. Good (1,2,3), Brian Zenger (1,2,3), Jake A. Bergquist (1,2,3), Karli Gillette (4), Gernot Plank (4), Rob S. MacLeod (1,2,3)

(1) Scientific Computing and Imaging Institute, University of Utah, Salt Lake City, UT, USA
(2) Department of Biomedical Engineering, University of Utah, Salt Lake City, UT, USA
(3) Nora Eccles Cardiovascular Research and Training Institute, University of Utah, Salt Lake City, UT, USA
(4) Medical University of Graz, Graz, Austria

Presentation Date and Time: Fri Apr 30 11:20:00 UTC 2021

Background: Accurate localization of premature ventricular contractions (PVCs) deep within the myocardium is a significant challenge with current techniques reporting large and unpredictable errors. Such techniques are based on endocardial mapping alone, however augmenting mapping with non-invasive electrocardiographic imaging (ECGI) could provide valuable missing information. In this study we will determine the feasibility and improvements in accuracy possible by integrating non-invasive ECGI activation maps with endocardial mapping to detect the depth and location of PVCs within the myocardium.

Methods: We used the Cardiac Arrhythmia Research Package (CARP) software to simulate activation from 7 PVC sites at varying depths throughout the myocardium and create the ground truth. To replicate contact mapping, we sampled activation times over the endocardial surface of the left ventricle at 1-2 mm resolution and estimated activation times throughout the myocardium using radial basis interpolation. We then added epicardial activation times, to emulate the augmentation provided by ECGI, and repeated the reconstruction of three-dimensional activation times and determined the PVC locations. The PVC localization error was determined by measuring the distance between the position chosen in the simulation and that recovered from the reconstruction. We also evaluated the accuracy of the reconstruction of activation waves by estimating the RMS error and the percent of activation times within 1 ms of the ground truth.

Results: Endocardial mapping alone produced wavefront reconstructions with an average RMSE of 8.1 +/- 2.8 ms and 36% of the nodes within 1 ms of the ground truth. The augmented approach reduced the average RMSE to 1.5 +/- 0.2 ms and reconstructed the wavefront with 64% of the nodes within 1 ms of ground truth. PVC localization using endocardial mapping alone produced errors of 0.5 +/- 17 mm, with the largest occurring from PVCs originating from the epicardium. The augmented approach improved the reconstruction, decreasing the error range to 0.5 +/- 4.5 mm, with the largest error occurring with mid-myocardial PVCs.
**Conclusions:** Augmenting endocardial mapping with epicardial activation times as estimated from ECGI has the potential to improve localization of PVCs within the myocardium. Feasibility studies are now necessary to confirm the practical utility of this approach as well as its sensitivity to inevitable errors in either mapping or ECGI.
The odyssey of acute myocardial infarction detection in automated ECG interpretation algorithms: The Denominator Challenge

Author(s): Ziad Faramand, MD;(a,d) Christian Martin-Gill, MD;(b,d) Clifton Callaway, MD, PhD;(b,d) Samir Saba, MD;(c,d) Stephanie O. Frisch, PhD(c) ;(a,d) Richard E Gregg, MS;(e) John Wang, MS;(e) & Salah Al-Zaiti, RN, PhD (a,b,c)

(a) Department of Acute & Tertiary Care Nursing;
(b) Department of Emergency Medicine;
(c) Division of Cardiology at University of Pittsburgh, PA, USA
(d) University of Pittsburgh Medical Center (UPMC), Pittsburgh PA, USA and
(e) Philips Healthcare, Andover, MA, USA

Presentation Date and Time: Fri Apr 30 11:50:00 UTC 2021

Background: Automated ECG interpretation algorithms report high performance accuracy for detecting acute myocardial infarction (MI). An operational definition of the population with the disease of interest (e.g. STEMI vs presence of culprit lesion), however, is often conjectural and remains elusive. In this study, we sought to explore the performance of an automated ECG interpretation algorithm in a population with undifferentiated prehospital chest pain by varying the choice of the actual underlying condition (i.e. the denominator) across a spectrum of acute ischemic cardiac events.

Methods: This was a secondary analysis of EMPIRE study that recruited consecutive, non-traumatic, chest pain patients with prehospital 12-lead ECG. All ECG signals (500 s/s with 0.05-150Hz bandwidth) were preprocessed by the Philips™ DXL diagnostic algorithm and then ECG criteria as per ACC/AHA guidelines were applied to denote the likelihood of acute MI alert. The patients were followed up for 30 days from indexed admission to adjudicate the following clinical events of interest: 1) STEMI with prehospital Cath lab activation, 2) confirmed STEMI at the emergency department, 3) presence of culprit lesion during catheterization, 4) type I or type II acute MI with leak of cardiac enzymes, and 5) any acute coronary syndrome (ACS) requiring anti-ischemic therapy.

Results: Our sample included 750 patients (mean age 59±17, 42% females, 40% blacks). There were 31 (4.1%) cases of prehospital STEMI activation, 53 (7.1%) cases of physician identified STEMI, 78 (10.4%) cases of Cath identified culprit lesions, 99 (13.2%) cases of type I/II acute MI, and 115 (15.3%) cases of ACS. Table 1 shows the diagnostic accuracy of the diagnostic algorithm in detecting these respective conditions with an acute MI alert. The performance progressively decreased when the condition of interest expanded to encompass a broader definition of ischemic cardiac events, with the highest performance observed for prehospital STEMI, and the lowest performance observed for ACS detection.

Conclusions: The performance of a STEMI algorithm could vary widely depending on the
clinical reference used in the assessment, with diminished performance among those with actionable cardiac events. In reporting diagnostic performance, automated ECG interpretation algorithms should provide a more elucidated and mutual definition of what the denominator of an acute MI alert should entail.
Characterization of impaired ventricular repolarization by quantification of QT delay after heart rate changes in stress test

Author(s): Cristina Parez (a,b), Esther Pueyo, PhD(a,b), Juan Pablo Martinez, PhD(a,b), Pablo Laguna, PhD(a,b)

(a) CIBER in Bioengineering, Biomaterials and Nanomedicine, Zaragoza, Spain
(b) BSICoS Group, Aragon Institute of Engineering Research (I3A), IIS Aragon, University of Zaragoza, Zaragoza, Spain

Presentation Date and Time: Fri Apr 30 12:30:00 UTC 2021

Background: A variety of ECG markers aimed at quantifying spatio-temporal heterogeneity of ventricular repolarization has been proposed to stratify patients for arrhythmic risk. One of those markers measures the adaptation of the QT interval to sudden abrupt heart rate (HR) changes as a first-order system response. Abrupt HR changes imply strenuous manoeuvers and are not easily observed in Holter recordings. In this work, the time lag between the actual QT series and the expected HR-dependent QT series is calculated from stress test recordings, hypothesizing that the time constant of the ramp-like HR change is the same as for the step response.

Methods: The dataset consisted of stress test ECG recordings from fourteen patients of the FINCAVAS database belonging to the group of low likelihood for Coronary Artery Disease group. QT(n) and RR(n) time series were computed by wavelet-based ECG delineation and outlier values were discarded. The expected HR-dependent QT interval series, (QT^), was calculated by fitting a parabolic regression model to the [QT(n), RR(n)] data pairs in three different windows representative of stationary QT-to-RR dependency: before, after and at the peak of the stress test. The time lag was estimated by a Mean Square Error fit between the QT response ramp and the (QT^) ramp, separately in the exercise, τ_s, and recovery, τ_r, phases.

Results: The average time lags across subjects (mean+/−standard deviation) were τ_s=41.9+/−24.3 and τ_r=29.7+/−13.8 s. These values are in line with those of a previous study estimated from step-like HR changes where values ranging from 35 to 57 s were reported. Nonetheless, the values from daily activities in Holter recordings from that study were τ_s=34.8+/−13.6 and τ_r=48.4+/−25.3 s for HR accelerations and decelerations, respectively. The longer adaptation time for HR acceleration vs HR deceleration in our study, as opposed to the other study, may be explained by different autonomic modulation of ventricular electrical activity in stress tests. As a particular observation, (QT^) and QT became overlapped with no significant delay time when approaching the stress peak. This is in agreement with a recent findings showing that the time for ventricular repolarization adaptation to sympathetic provocation becomes progressively reduced for increasingly higher levels of beta-adrenoceptorsâ€™ stimulation, as occurs when approaching the stress peak.
Conclusions: This study shows the feasibility to measure QT hysteresis in response to gradual HR changes, as in stress test, advocating for further studies to explore its value as a sudden cardiac death predictor.
Significant Improvement in Automated STEMI Detection by Modeling the ST Segment

Author(s): Reza Firoozabadi, PhD, Richard Gregg, MS, Saeed Babaeizadeh, PhD
Advanced Algorithm Research Center, Philips Healthcare, Andover, MA, USA

Presentation Date and Time: Fri Apr 30 12:30:00 UTC 2021

Background: Accurate analysis of the ST segment is critical in diagnosis of the ST segment elevation myocardial infarction (STEMI). Negligible to high levels of artifact from different sources may be present throughout the ST segment. Superficial elevation of the ST segment in an ECG record could either mimic a nonexistent ST elevation, resulting in a false STEMI diagnosis, or deviate the level of an existing ST elevation and negatively impact the precise diagnosis of the underlying disease. Averaging the beats in an ECG interval reduces the artifact level on the ST segment, but does not eliminate it entirely. In this study, we present and compare two correction methods for the ST level measurement.

Methods: We studied two approaches for improving the ST segment analysis, compared to simply using the raw average ST segment waveform: a short-duration smoothing window and an ST segment curve-fitting model. The smoothing approach used quadratic polynomial least-squares approximation of the average ST segment in a time window of up to 20 milliseconds. The curve-fitting method modelled the ST segment by a section of a parabola using a quadratic polynomial equation. A modified version of Philips DXL(TM) algorithm was used to analyze the 12-lead 10-second recordings for various cardiac conditions including STEMI.

Results: Our test database included 146,349 recordings from a single medical center, and contained 2,524 STEMI recordings (prevalence of 1.7%) marked by a human expert. Running the algorithm, we compared its STEMI detection performance for the raw average, smoothed, and curve-fitted ST segments. Table 1 summarizes the performance. A 20-fold decrease in the number of false positives (FP) is observed after smoothing or curve-fitting. The curve-fitting method had 121 fewer FPs than smoothing, but resulted in more false negatives. The better performance of curve fitting could be because it is always uniform in the ST segment, but the short-duration smoothing may follow the trend of the slow-varying or high amplitude artifact. The increase in false negatives was observed which was mostly in recording with moderate level of noise where waveform artifact mimicked border-line ST elevations.

Conclusions: It is possible to significantly reduce the number of the false STEMI detections by either smoothing or curve-fitting of the ST segment instead of analyzing the raw average waveform.
A Composite Signal Quality Index for Analysis of the Large ECG Datasets

Author(s): Sara Mariani, PhD (1), Saeed Babaeizadeh, PhD (2), Reza Firoozabadi, PhD (2), Wei Zong, PhD (2)

(1) Philips Research North America, Cambridge, MA, USA
(2) Advance Algorithm Research Center, Philips Healthcare, Cambridge, MA, USA

Presentation Date and Time: Fri Apr 30 12:30:00 UTC 2021

Background: Automated analysis of the large ECG datasets requires effective and efficient methods to identify artifacts due to the patient movement, baseline wander, poor electrode contact, and/or electrical interference. We present a composite signal quality index (cSQI) that scores ECG quality on a second-by-second basis.

Methods: In this study, we combined eight noise indices into cSQI: 1) Low-frequency noise, based on low-pass recursive filtering; 2) High-frequency noise, based on second-order differences; 3) Flat-line ratio; 4) Peak-to-peak amplitude; 5) Spikes in signal, encompassing maximum signal slope and amplitude; 6) Signal saturation duration; 7) Power-line noise, encompassing the band-pass filtered signal amplitude and SNR; and 8) Outliers of the detected RR intervals. Thresholds for each noise index were determined empirically. The cSQI is zero (poor signal) if at least one index exceeds its threshold; otherwise it is 1 (acceptable signal). To evaluate the cSQI, we used ECG records from the MIT-BIH normal sinus rhythm database. For each signal, we visually selected one or two noise-free episodes (n=31), each between 15-min and 2-hr long (total 85,887sec). Noise records with three major types in the MIT-BIH Noise Stress Test database were used. We randomly selected 10-sec segments from each type of the noise in individual records and superimposed them in random locations on the clean ECG records, so that approximately 20% of the signal was noisy. We imposed SNR levels of 0dB, -6dB, and -10dB. The performance was evaluated by assessment of the noise presence in all 1-sec intervals (n=85,887): A TP event was the recognition of a noisy interval, while a TN event was detection of a clean interval. The FP and FN events were defined similarly.

Results: The proposed cSQI achieved 49% sensitivity and 100% specificity with SNR=0dB, 77% sensitivity and 99% specificity with SNR=6dB, and 89% sensitivity and 98% specificity with SNR=-10dB. We also utilized the cSQI to discard artifacts from 11,000+ long-term ECG records (from ICUs) prior to the extraction of time-domain HRV and morphology features. To visual assessment, the features with cSQI control showed smoother trends and much fewer outliers while preserving the trend dynamics, as compared to those without cSQI control. The cSQI algorithm took 52 seconds to process a 24-hr ECG record in Matlab on a Windows PC (2.50 GHz, 8 GB RAM).
Conclusions: The proposed cSQI is capable of effectively and efficiently detecting the major types of ECG artifact and may be employed in analysis of large ECG datasets.
Diagnostic and prognostic value of ST-segment deviations in patients with suspected myocardial infarction and right bundle branch block

Author(s): Mohammad Toma, MD (a,b), Yama Fakhri, MD, PhD (c), Hedvig Andersson, MD, PhD (c), Mathilde Jessen, MD (d), Lisette Jensen, MD, DMSc (b,d), Lene Holmvang, MD, DMSc (c), Peter Clemmensen, MD, DMSc (a,b,e)

(a) Department of Medicine, Division of Cardiology, Nykøbing F Hospital, Nykøbing F, Denmark; (b) Institute of Regional Health Research, University of Southern Denmark, Odense, Denmark; (c) Department of Cardiology, Rigshospitalet, University Hospital, Copenhagen, Denmark; (d) Department of Cardiology, Odense University Hospital, Odense, Denmark; (e) University Clinic Hamburg-Eppendorf, The Heart Center, Department of General and Interventional Cardiology, Hamburg, Germany

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Background: Diagnosis of myocardial infarction (MI) is challenging, especially in patients with right bundle branch block (RBBB). RBBB is a high-risk feature in patients with suspected myocardial infarction (MI) and urgent coronary angiography (CAG) should be considered. The primary aim of this study was to determine the association between RBBB on the presenting electrocardiogram (ECG) in chest pain patients and the chance of performing primary percutaneous coronary intervention (PCI). Secondary aims were to investigate differences in baseline characteristics in patients treated with and without PCI and their subsequent all-cause mortality.

Methods: All patients with suspected MI, RBBB on the presenting ECG, and a subsequent diagnostic CAG were included in the study. We enrolled 6102 consecutive patients from two large primary PCI centers in Denmark with suspected MI, Rigshospitalet n = 2276 and Odense University Hospital n = 3826. Clinical characteristics and comorbidities were identified at baseline. Prehospital ECGs were retrospectively analyzed to identify RBBB presenters. ST-deviations in patients with RBBB were analyzed for each individual lead. Procedural characteristics including TIMI flow grade were performed before and after intervention in the PCI group and the primary endpoint was all-cause mortality by PCI status.

Results: Out of 6102 patients with suspected myocardial infarction, 177 patients (2.9%) presented with RBBB in the prehospital ECG and were included in the study. In total, 19 (10.8%) patients were not treated and 158 (89.3%) were treated with PCI. Both groups had similar baseline characteristics. Primary endpoint of all-cause mortality was reached in 16 (84.2%) patients in the non-PCI group versus 48 (30.4%) patients in the PCI group (P-value = 0.409) giving an increased risk of death in patients without PCI with a hazard ratio [HR] of 1.658 (95% confidence interval 0.500 to 5.495). The following table summarizes baseline, electrocardiographic and procedural characteristics as well as mortality in patient with...
suspected acute MI presenting with RBBB, according to whether patients have been treated with primary PCI or not.

**Conclusions:** We conclude that the majority of patients with suspected MI and RBBB undergoing CAG are treated with primary PCI. RBBB in acute coronary syndrome (ACS) presenters is associated with an extremely high mortality, regardless of initial treatment strategy. Based on summated ST deviation or number of leads with ST-segment elevation, the acute prehospital ECG does not seem to predict the likelihood of a PCI culprit artery in ACS patients with RBBB.
ECGI for Cardiac Resynchronization Therapy: Technical Challenges and Clinical Benefits

**Author(s):** D. Potyagaylo (1), M. Chmelevsky (1,2), M. Budanova (2), S. Zubarev (2), T. Treshkur (2), D. Lebedev (2)

(1) EP Solutions SA, Yverdon-les-Bains, Switzerland
(2) Almazov National Medical Research Center, Saint-Petersburg, Russia

**Presentation Date and Time:** Fri Apr 30 12:30:00 UTC 2021

**Background:** ECG imaging (ECGI) is a technology with great clinical potential for non-invasive diagnostics and pre-operative planning in patients with heart rhythm disturbances. Currently available commercial ECGI systems are based on multi-channel ECG recordings with up to 240 leads. In the present work, we assess robustness of the ECGI technique with respect to a reduced number of electrodes and investigate how the best electrode positions correlate across the patients.

**Methods:** We performed ECGI for 30 consecutive cardiac resynchronization therapy (CRT) patients with left- and right-ventricular (LV and RV) isolated stimulation and seven patients with RV pacing only. For non-invasive reconstruction of pacemaker lead locations, we used a multi-channel ECG system with Tikhonov regularization. The median number of electrodes was 197 in the range 130–240. Afterwards, we randomly excluded 10 to 90% of the available electrodes with a 10% step. For each step, 150 exclusion permutations were analyzed. For all patients and electrode configurations, we calculated ECGI localization errors (LEs) between non-invasively reconstructed and CT-based pacing lead locations. Then we computed median LEs within each lead setup consisting of 150 samples for every patient. From these individual median values, we determined median and range LEs for all considered patients. Furthermore, we analyzed incidence rates for the electrodes from 90%-exclusion setups, resulting in minimal LEs, on a template body surface clustered in 25 segments, and assessed performance of an optimal reduced 16-lead system.

**Results:** Surprisingly, excluding 10, 50, and 90% of originally available electrodes resulted in 18 (1; 74), 18 (1; 74), 19 (2; 74) mm median accuracy, respectively. The most common electrode clusters located on the upper middle and right back together with the precordial clusters exhibited the highest incidence rates in the individually best 90%-exclusion setups. The found optimal 16-leads setup resulted in 7 (1; 23) mm LE across the patients.

**Conclusions:** ECGI based on multi-channel (more than 200 leads) ECG recordings is robust against random drop-off of up to 90% of the available electrodes, making this technology suitable for everyday clinical EP work. Superior performance of the found lead-reduced system might be associated with the drawbacks of Tikhonov regularization. This observation could also
indicate that errors in the volume conductor model might overweight the information content gained from a multi-lead system covering the whole torso.
Improving non-invasive prediction of the PVC origin using the standard 12-lead ECG

**Author(s):** Roger Abächerli (a,d), Peter Michael van Dam (a), Ivo Strebel (b) l, Sven Knecht (b), Florian Spies (b), Martim Kastelein (c), Michael Kühne (b), Christian Sticherling (d), Tobias Reichlin (b)

(a) Institute of Medical Engineering, Luzern, Switzerland,
(b) University Hospital Bern, Bern, Switzerland ,
(c) Peacs BV, Nieuwerbrug, Netherlands, d University Hospital Basel, Basel, Switzerland

**Presentation Date and Time:** Fri Apr 30 12:30:00 UTC 2021

**Background:** RF-Catheter ablation is a procedure that is frequently performed in the case of premature ventricular contractions (PVCs). Preliminary localization of the PVC origin-site is critical to the precision-planning of the catheter route. A VCG-based method has proven to be as accurate in the prediction of the heart chamber as clinicians. The objective of the study was to improve the method such that it will outperform the clinicians.

**Methods:** A cohort of patients consecutively undergoing idiopathic PVC ablation was enrolled. The PVC origin-site was defined to be the site at which the procedure succeeded in eliminating the PVC. Patients with unsuccessful ablation or with scars were excluded. Every baseline 12-lead ECG was analyzed in a manually blinded fashion by seven electrophysiologists (EPs) and the algorithm. Importantly, the VCG-based algorithms did not rely on patient-specific MRI models in order to have conditions equal to that of human experts.

**Results:** Of the 29 patients undergoing the analysis the median age was 55 years, of which 72% were females, median LVEF was 59% and median PVC-burden prior to ablation was 19%. The site of origin was localized to the right ventricle (RV) in 17 patients (59%). Manual analysis by the EPs achieved a mean accuracy of 81.3% (std: 5.8%, range: 72-90%) while the algorithm achieved an accuracy of 85.7% with an average error of 6.8mm (std: 5.2mm, range: 2.8-21.6mm).

**Conclusions:** The study results demonstrate that given VCG-based algorithm employing standard 12 lead ECG data and assuming a standard torso/heart model is capable of localizing the PVC’s site of origin to either heart chamber with an accuracy that is slightly higher than that of EPs (86% vs. 81%).
Characteristics on the Admission 12-Lead ECG Prognostic of Re-Infarction and Death among UA/NSTEMI Patients: A Protocol and Preliminary Results for a Systematic Review & Meta-Analysis

Author(s): Dillon J. Dzikowicz BS, RN, Mary G. Carey PhD, RN, FAHA

School of Nursing, University of Rochester, Rochester, NY, USA

Presentation Date and Time: Fri Apr 30 12:30:00 UTC 2021

Background: UA/NSTEMI remains a leading cause of death among patients with coronary artery disease. The identification of hallmark ECG abnormalities such as ST-segment depression or serial T wave changes on the admission 12-lead ECG helps identify the presence of myocardial ischemia and increased risk for re-infarction and death; however, new evidence suggest QTc interval prolongation, prolong QRS duration, fQRS complexes, pathological Q waves, and suppressed HRV may add additional prognostic value. The purpose of this study is to evaluate and assess the relative risk (RR) of re-infarction and death per each unique characteristic on the admission 12-lead ECG among UA/NSTEMI patients.

Methods: A systematic review is currently being conducted using the following databases: Web of Science, Medline, Embase, PubMed, and CINAHL as well as 10 cardiovascular journals. The following keywords are being used: ECG, mortality, prediction, risk assessment, risk factors, RR/odds ratio, MI, NSTMI, myocardial ischemia, emergency medicine/service, and emergency nursing. Inclusion criteria: full-text peer-reviewed publications in English; patient presenting with suspected UA/NSTEMI; admission 12-lead ECG; use of a statistical outcome to assess associated risk. Exclusion criteria: STEMI; serial ECG; derived 12-lead ECG; and continuous 3-lead, 5-lead or 12-lead ECG. Quality will be assessed using the Newcastle-Ottawa Quality Assessment Scale. This systematic review is under consideration for registration with PROSPERO. A random-effects meta-analytic power analysis was conducted; assuming a small effect size (cohenâ€™s d of 0.2), an average number of 150 participants per group, and high intrastudy study heterogeneity, a minimum of 1,050 study participants distributed across 7 individual studies will be necessary to achieve a type I/ type II error rate of 5%/10%, respectively. RR with 95% confidence intervals will be calculated; Q and I2 will be calculated to measure heterogeneity. Forest plots will be produced to assess bias. p<0.05 for significance.

Results: Thus far, 23 studies have been included. ST-segment depression was the most common characteristic, accounting for 48% (n=11) of all included studies. Additionally, 22% (n=5) of studies evaluated T-wave changes, 9% (n=2) assessed QTc interval prolongation, 9% (n=2) measured prolong QRS duration, 4% (n=1) focused on pathological Q waves, 4% (n=1) evaluated fQRS complexes, and 4% (n=1) examined LVH. Interestingly, 9% (n=2) assessed anterior-lead specific ST-segment depression, and 13% (n=3) assessed ST-segment changes in lead aVR.
**Conclusions:** This ongoing systematic review and meta-analysis will fully-evaluate existing literature and assess the RR of re-infarction and death per each unique characteristic on the admission 12-lead ECG among UA/NSTEMI patients.
T wave morphology in Long QT Syndrome

Author(s): Alan Sugrue

Presentation Date and Time: Sat May 01 08:00:00 UTC 2021

There has been remarkable advancement and evolution in our understanding of Long QT syndrome since Jervell and Lange Nielsen first described four patients in a family of 6 who had congenital deafness, QT prolongation, and sudden death. Early studies marveled at QT prolongation, but it was not until the mid-1990s that phenotypic T wave changes were discovered and soon became an integral part of the diagnosis and understanding of LQTS. The initial focus on the T wave was identified manifest changes, but there has been an incredible advancement in computerized automated architectural analysis in the last ten years. Seminal papers by Moss and Dausse form the basis of our current understanding of the T wave in LQTS. Specifically, those with a chromosome 11 mutation (LQT1) had a broad-based prolonged T wave pattern, while those with a chromosome 7 mutation (LQT2), the T wave was moderately delayed (often notched or biphasic), and patients with an SCN5A mutation (LQT3) had a distinctly, later appearing T wave. Regarding computerized analysis, our group at the Mayo Clinic and others have repeatedly shown that subtle changes in the T wave architecture can help diagnose and identify those at the greatest arrhythmic risk. Specifically, we developed a software package in MATLAB to facilitate architectural T-wave analysis. This software provides automatic 12-lead ECG T wave feature detection and extraction for a range of features. In LQTS patients, a combination of T wave features was able to distinguish patients with either LQT1/LQT2 from healthy matched controls (Tpeak–Tend interval, T wave left slope, and T wave center of the gravity x-axis (last 25% of the T wave)), including those with a concealed phenotype (normal resting QTc). T wave analysis has also provided prognostic information identifying those at risk of future LQTS arrhythmic events (Left slope of T wave in lead V6 and T wave center of gravity x-axis (last 25% of wave) in lead I). Further, it could differentiate acquired from drug-induced QT prolongation (T wave right slope, T-peak-Tend interval, T wave center of gravity on the x-axis). In conclusion, although QT prolongation is the LQTS hallmark feature, many patients with clinically and genetically confirmed LQTS have an otherwise normal-looking ECG (40%). T wave analysis provides insight into subtle changes and can be helpful with diagnosis and prognosis.
Heart Rate and QT Variability in the Long QT Syndrome

Author(s): Wojciech Zareba, MD, PhD, Jean-Philippe Couderc, PhD, MBA, Jean Xia, PhD

University of Rochester Medical Center, Rochester, NY

Presentation Date and Time: Sat May 01 08:30:00 UTC 2021

Long QT syndrome (LQTS) is an inherited arrhythmia disorder associated with QTc prolongation in ECG and propensity to life-threatening ventricular tachyarrhythmia that may lead to sudden cardiac death. QTc prolongation on ECG is highly predictive for arrhythmic events in LQTS patients, but over 50% of patients with LQTS present with QTc in the normal or borderline (470 ms) range. Therefore, a better understanding of clinical and genetic factors, and ECG features that might predispose to arrhythmic events is needed. T wave morphology plays an important role in diagnosing especially borderline QTc long QT syndrome cases and also helps in prognostication among patients with normal or mildly prolonged QTc. Since heart rate and QT demonstrate substantial variability in response to biological and physiological analysis of heart rate variability (HRV) and QT variability (QTV) might enhance our understanding of the LQTS and its heterogeneity of phenotypic presentations. There are controversial data regarding results of HRV analyses in comparison to control subjects, some studies finding lower sympathetic modulation in LQTS patients, other finding no difference, and other indicating that preserved or high parasympathetic modulation might be predisposing to events. Increased QTV seems to be associated with cardiac events in LQTS patients, but it seems that underlying sympathetic-parasympathetic modulation might play crucial role in arrhythmogenic response in LQTS patients. Therefore, a complex analysis taking into account QTc duration, type of genetic mutation, heart rate, heart rate variability and QT variability is needed to identify patients at higher risk of cardiac events.
Identification of hERG blockade by machine learning

Author(s): Micaela Morettini, PhD, Eugenia De Remigis, BSc, Agnese Sbrollini, PhD, Ilaria Marcantoni, MSc, Laura Burattini, PhD

Presentation Date and Time: Sat. May 01 09:10:00 UTC 2021

Background: Blockade of hERG potassium channel induced by some pharmacological treatments could predispose to development of Torsade-de-Pointes (TdP). However, drugs that block hERG may also block other ion channels (i.e. sodium and calcium), hence mitigating TdP risk. Thus, in order to obtain an improved TdP risk prediction when designing new drugs, there is the need to study multiple distinct ionic channels which are responsible for TdP. Blockade of hERG affects T-wave morphology on the electrocardiogram (ECG) and a machine-learning approach, based on artificial neural network (ANN), has been recently proposed for the ECG-based classification of such blockade. This study aimed to extend this approach to the detection of hERG potassium channel blockade independent from concomitant sodium and/or calcium blockade.

Methods: The data were taken from the ECG Effects of Ranolazine, Dofetilide, Verapamil, and Quinidine in Healthy Subjects. Physionet database; they consisted of median vector magnitude (VM) beats of 22 healthy subjects receiving a single 500 mg dose of dofetilide (pure hERG potassium channel blocker) and, in a separate day, 1500 mg of ranolazine (hERG and calcium/sodium currents blocker). A total of twenty-eight VM beats were considered for each subject, relative to time points ranging from 0.5 hr before to 14.0 hr after dofetilide or ranolazine administration (fourteen VM beats for each drug). For each VM, changes in the two indexes ERD30% and TS/A, accounting for the early and the late phases of repolarization, respectively, were computed as difference between values at each postdose time-point and the predose timepoint. Thus, the dataset contained 286 ERD30% TS/A pairs for the dofetilide administration and 286 ERD30% TS/A pairs for the ranolazine administration. Firstly, the overall 572 ERD30% TS/A pairs and secondly, only the 286 ERD30% TS/A pairs related the dofetilide administration were randomly partitioned into training (40%), validation (10%), and test (50%) sets and used as inputs of a two-layer feedforward ANN with 18 neurons in the hidden layer and two target classes: high blockade (HB) and low blockade (LB). For the test, the two receiver operating characteristics (ROC) were compared by using Venkatraman test (p<0.05).

Results: Test-set area under the ROC was 0.90 and 0.91 in dofetilide+ranolazine and dofetilide dataset, respectively; no statistical difference between the two ROC was observed (p=0.26). Accuracy was 0.82 and 0.92 in dofetilide+ranolazine and dofetilide dataset, respectively.

Conclusions: The proposed machine-learning approach proved to be reliable for the detection of hERG potassium channel blockade independent from concomitant sodium and/or calcium blockade.
Depolarization disturbances in ARVC

Author(s): Pyotr G Platonov, MD, PhD

Lund University and Skane University Hospital, Lund, Sweden

Presentation Date and Time: Sat May 01 09:40:00 UTC 2021

Arrhythmogenic right ventricular cardiomyopathy (ARVC) is an inherited heart disease, which is associated with abnormal function of desmosomal proteins resulting in disintegration of myocardium and its replacement with fibrotic tissue. This process results in development of substrate for ventricular arrhythmias and increased risk of sudden death, which commonly occurs at young age. Disturbances of depolarization wave propagation through myocardium in patients with ARVC is a direct consequence of fibrotic replacement of cardiomyocytes in the ventricular myocardium and may be reflected on surface ECG as prolongation of QRS complex, development of QRS fractionation and specific ECG phenomena described in the context of ARVC as epsilon wave and terminal activation delay (TAD) in right precordial leads. Depolarization abnormalities have been considered as major (epsilon wave) or minor (TAD or late potentials by signal-averaged ECG) diagnostic criteria for ARVC by Task Force consensus from 2010. Despite being used in clinical practice over long time, major depolarization abnormality (epsilon wave) remains poorly defined, and its interpretation is subjected to substantial interobserver variability that hampers its use as a diagnostic marker. There are controversial data regarding reproducibility of depolarization abnormalities over long period of time, which may affect ARVC diagnosis. Studies on digital ECG archives that accumulate large number of ECG recorded over a long period of time offer an opportunity to study longitudinal changes in ventricular depolarization markers beyond conventionally defined diagnostic criteria and can be particularly valuable for detection of early signs of the disease.
Computerized ECG analyses of Brugada Syndrome

Author(s): Fabrice Extramiana, MD, PhD
Paris, France

Presentation Date and Time: Sat May 01 10:10:00 UTC 2021

The Brugada syndrome is a rare inherited arrhythmic syndrome associated with an increased risk of sudden cardiac arrest and death. The diagnosis of the syndrome requires the presence (either spontaneous or after class I antiarrhythmic drug challenge) of a coved type ST segment elevation >200µV followed by a negative T wave on at least one precordial lead. Phenocopy and the changing and/or incomplete ECG pattern over time can make the diagnosis difficult and in many cases, a potentially dangerous drug challenge is required to ascertain the diagnosis. However, risk stratification remains the main challenge in Brugada patients, especially in asymptomatic ones. Under the hypothesis of a relationship between the nature and degree of ECG abnormalities and the arrhythmic substrate, many studies have evaluated the risk stratification performance of ECG derived quantitative parameters.

Accordingly, the Brugada syndrome looks like an ideal playground for computerized ECG analyses. However, most of the historical Brugada patient cohorts include only paper ECGs. We will discuss the proposed quantitative ECG parameters for diagnosis and risk stratification for the Brugada syndrome as well as futures directions for computerized ECG analyses.
ECGI for Cardiac Resynchronization Therapy: Technical Challenges and Clinical Benefits

Author(s): Peter M. Van Dam, PhD,(1,3), Machteld J Boonstra, MSc,(1), Emanuela T. Locati MD, PhD (2), Peter Loh, MD, PhD (1)

(1) Department of Cardiology, University Medical Center Utrecht, The Netherlands
(2) Department of Arrhythmology and Electrophysiology, IRCCS Policlinico San Donato, Milano, Italy
(3) ECG Excellence BV, Nieuwerbrug aan den Rijn, Netherlands

Presentation Date and Time: Sat May 01 10:50:00 UTC 2021

Background: Conventional ECG based diagnosis is solely based on the comparison of waveforms. Only ECG experts are able to relate the ECG waveforms to the 3D cardiac anatomy. Consequently classification of ECG waveforms can be ambiguous, e.g. left BBB can be difficult to detect in patients with left ventricular hypertrophy, whereas the definition of incomplete and complete right BBB is solely based on ECG waveforms and not on the electro-physiological activation of the heart. With CineECG the mean position of cardiac activation and recovery can be directly related to the cardiac anatomy. In this study we investigate the CineECG pathway for activation and recovery for normal ECGs.

Methods: We developed a new inverse ECG method, CineECG, to study the cardiac activation and recovery pathway by deriving the mean temporal spatial isochrone (mTSI) from the recorded 12-lead ECG. The mTSI describes the trajectory of the average electro-anatomical pathway within a cardiac anatomy. This enables the quantification of the activation progression to specific cardiac areas, such as the right or left free wall. In total 3500 ECGs, classified as normal, were taken from the Physionet PTB XL Diagnostic ECG Database. For each of these ECGs the CineECG was constructed using standard electrode positions and a standard cardiac anatomy.

Results: The 3500 CineECG’s were analyzed per age group (18-30, 30-40, 40-50, 50-60, 60-70, 70-100 years). Each of the ECGs were plotted on the 3 heart axes, posterior-anterior (X axis), right to left (Y axis), and apex to base (Z-axis). The typical normal CineECG showed a rather compact pathway for the QRS, whereas the terminal T-wave pathway, from Tpeak to Tend, always moved in a base to apex direction. The standard deviation in terminal T-wave position was relative small and similar for all age groups (11.2 mm). The standard deviation in the QRS and initial T-wave positions was larger (26.1 mm, 17.0 mm respectively), which might be attributed to the variation in both individual heart orientation and the initiation by the His-Purkinje system.

Conclusions: This study showed that the CineECG for normal ECGs follows a typical pathway of the normal and left and right bundle branch block pattern. This electro-anatomical view on the
ECG might enable the standardization of the normal ECG wave patterns and thus enable easier detection of abnormal ECG wave patterns. Further research is required to investigate the influence of heart orientation on the CineECG.
Normal Cine-electrocardiogram: Can We Standardize the ECG to the Cardiac Anatomy?

Author(s): Peter M. Van Dam (PhD) 1,3, Machteld J Boonstra (MSc) 1, Emanuela T. Locati MD (PhD) 2, Peter Loh (MD PhD) 1

1 Department of Cardiology, University Medical Center Utrecht, The Netherlands
2 Department of Arrhythmology and Electrophysiology, IRCCS Policlinico San Donato, Milano, Italy
3 ECG Excellence BV, Nieuwerbrug aan den Rijn, Netherlands

Presentation Date and Time: Sat May 01 11:20:00 UTC 2021

Background: Conventional ECG based diagnosis is solely based on the comparison of waveforms. Only ECG experts are able to relate the ECG waveforms to the 3D cardiac anatomy. Consequently classification of ECG waveforms can be ambiguous, e.g. left BBB can be difficult to detect in patients with left ventricular hypertrophy, whereas the definition of incomplete and complete right BBB is solely based on ECG waveforms and not on the electro-physiological activation of the heart. With CineECG the mean position of cardiac activation and recovery can be directly related to the cardiac anatomy. In this study we investigate the CineECG pathway for activation and recovery for normal ECGs.

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Conclusions: This study showed that the CineECG for normal ECGs follows a typical pathway of the normal and left and right bundle branch block pattern. This electro-anatomical view on the ECG might enable the standardization of the normal ECG wave patterns and thus enable easier
detection of abnormal ECG wave patterns. Further research is required to investigate the influence of heart orientation on the CineECG.

Figure 1 The CineECG of a normal ECG. White is the start of the QRS, trans-septal vector, read the QRS, yellow the ST segment and blue the T-wave. Notice the base-apex direction of the terminal T-wave.
Mapping Ventricular Arrhythmias with ECG Imaging

Author(s): S. Suave Lobodzinski
California State University
Long Beach, California

Presentation Date and Time: Sat May 01 11:50:00 UTC 2021

Electrocardiographic Imaging (ECGI) is a noninvasive 3D Mapping method for cardiac potential imaging using body surface ECG signals. Together with geometrical information from CT or MRI torso scans and mathematical modeling reconstruct electric potentials, electrograms, activation sequences and repolarization patterns on the surface of the heart. ECGI is therefore capable of producing and displaying simultaneous, bi-atrial and biventricular, 3-D cardiac maps, which in turn should enable physicians to characterize abnormal rhythms of the heart.

This noninvasive imaging modality for cardiac arrhythmias continues its development despite some serious challenges. The ECGI must overcome barriers before it can be routinely used in clinical practice:

- The accuracy of ECGI in structural heart disease remains uncertain.
- No clearly defined / proven clinical benefits in terms of outcomes for specific arrhythmias.
- Physicians don’t feel ECGI provides significantly better outcomes to warrant additional time and expense.
- Lack of needed accuracy for most interesting clinical applications, e.g. unstable VT, VF / AF.
- Lack of clinical significance validation by clinical investigations of solely utilizing phase maps to classify arrhythmia mechanisms.
- High cost (without adequate reimbursement).
- Physicians are not familiar enough with the ECGI technology.

However, despite its present-day limitations, ECGI represents a significant advancement over standard procedures in contemporary cardiology. Its full potential has yet to be fully realized.
Brazil
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Sweden
Switzerland
United Kingdom
United States
Roger Abächerli, M.D., Ph.D.  
Hochschule Luzern  
Switzerland  
roger.abaecherli@hslu.ch

David Albert  
AliveCor, Inc.  
United States  
drdave@alivecor.com

Saleh Aliyari  
Caltech (Previous employer Adelphi university i-797 valid through September 10)  
United States  
saliyari@alumni.iu.edu

Salah Al-Zaiti, Ph.D.  
University of Pittsburgh  
United States  
ssa33@pitt.edu

Alan Andresen  
Inovise Medical, Inc.  
United States  
andresen@inovise.com

Saeed Babaeizadeh, Ph.D.  
Philips Healthcare  
United States  
saeed.babaeizadeh@philips.com

Lorenzo Bachi  
Cardioline S.P.A.  
Italia  
lorenzo.bachi@santannapisa.it

Fabio Badilini  
AMPS LLC  
United States  
badilini@amps-llc.com

Ben Bailey  
Philips Healthcare  
United States  
ben.bailey@philips.com

Terry Bauch  
Geisinger Heart Hospital MC 36-10  
United States  
bauchmail432cardio@fastmail.com

Dennis Bergau, Ph.D.  
AbbVie  
USA  
dennis.bergau@abbvie.com

Raymond Bond, Ph.D.  
Ulster University  
United Kingdom  
rb.bond@ulster.ac.uk

Jimo Borjigin, Ph.D.  
University of Michigan  
United States  
borjigin@umich.edu

Zeineb Bouzid  
University of Pittsburgh  
United States  
zeb12@pitt.edu

Rob Brisk, M.D., Ph.D.  
Ulster University  
United Kingdom  
robrisk@hotmail.com

Laura Burattini, Ph.D.  
Università Politecnica delle Marche  
Italy  
l.burattini@univpm.it

Werner Bystricky  
TSD  
Deutschland  
werner.bystricky@abbvie.com

Timothy Callahan  
BioTel Research  
United States  
drtimcallahan@gmail.com
Mary G. Carey  
*University of Rochester Medical Center*  
United States  
mary_carey@urmc.rochester.edu

Jonas Carlson  
*Lund University*  
Sweden  
Jonas.Carlson@med.lu.se

Yu Chen  
*Draeger*  
USA  
yu.chen@draeger.com

W. Brian Chiu  
*Avicena LLC*  
United States  
brian@avicenaheart.com

MS Choi, M.D.  
*Sun GH*  
south korea  
choiminseok2k@gmail.com

Jean-Philippe Couderc  
*ISCE*  
United States  
heartjpc@gmail.com

Guldenring Daniel, Ph.D.  
*HS Kempten*  
Germany  
daniel.gueldenring@hs-kempten.de

Willem Dassen, Ph.D.  
*Maastricht University*  
Netherlands  
willem.dassen@mumc.nl

Johan De Bie,  
*Hillrom - Welch Allyn Cardiology*  
Italy  
johannes.debie@hillrom.com

Jim DeMaso  
*Global Instrumentation, LLC*  
United States  
jimdemoso@msn.com

Barbara Drew, Ph.D.  
--None--  
United States  
barbara.drew@ucsf.edu

Ruth Durie  
*Spacelabs Healthcare Ltd.*  
United Kingdom  
ruth.durie@spacelabs.com

Dillon Dzikowicz  
*University of Rochester School of Nursing*  
United States  
Dillon_Dzikowicz@URMC.Rochester.edu

Johan Eckerdal  
*Zenicor Medical Systems AB*  
Sverige  
jeckerdal@yahoo.se

Fabrice Extramiana, M.D., Ph.D.  
*Bichat hospital APHP - Université© de Paris*  
France  
fabrice.extramiana@aphp.fr

Yama Fakhri, M.D., Ph.D.  
*Zealand University Hospital*  
Danmark  
yfakhri@gmail.com

Ziad Faramand, M.D.  
*University of Pittsburgh*  
USA  
zif10@PITT.EDU

Robert Farrell, Ph.D.  
*GE Healthcare*  
United States  
robert.farrell@med.ge.com
Dewar Finlay, Ph.D.
University of Ulster
United Kingdom
d.finlay@ulster.ac.uk

Reza Firoozabadi, Ph.D.
Philips Healthcare
United States
r.firoozabadi@yahoo.com

Loriano Galeotti, Ph.D.
Food and Drug Administration
US
loriano.galeotti@fda.hhs.gov

Mengqi Gao
Philips Healthcare
US
mengqig@gmail.com

Gianluca Generali
Schiller AG
Switzerland
gianluca.generali@schiller.ch

Paulo Gomes
Telehealth center of HC-UFMG
Brazil
prxgomes@gmail.com

Wilson Good, Ph.D.
Acutus Medical / SCI Institute
United States
wilsonwgood@gmail.com

Claus Graff, Ph.D.
Aalborg University
Denmark
cgraf@hst.aau.dk

Richard Gregg
Philips Healthcare
United States
rich.gregg@philips.com

Bakir Haidarevic
Hillrom - Welch Allyn Cardiology
USA
Bakir.Hajdarevic@hillrom.com

David Hampton
Stone Bridge Biomedical
Netherlands
david.r.hampton@live.com

Patricia Harris, Ph.D.
Dominican University of California
United States
patricia.harris@dominican.edu

Eric Helfenbein
Philips Healthcare
USA
eric.helfenbein@philips.com

Thomas Hilbel, M.D.
University Hospital Heidelberg Germany
Germany
thomas.hilbel@w-hs.de

Aleeha Iftikhar, Ph.D.
University of Ulster
United Kingdom
Iftikhar-A1@ulster.ac.uk

Magnus Jensen, M.D., Ph.D.
Copenhagen University Hospital Amager Hvidovre
Denmark
magnustjensen@gmail.com

Jens Kandziora
University Hospital Germany, Dept. of Cardiology
Germany
Jens.Kandziora@studmail.w-hs.de

Jørgen Kanters, M.D.
University of Copenhagen
Denmark
jkanters@sund.ku.dk
Frank Keane  
Vitalograph  
Ireland  
Frank.keane@vitalograph.ie

Antoun Khawaja  
Khawaja Medical Technology GmbH  
Germany  
antoun.khawaja@khawaja-medtech.com

Miguel Kirsch  
AliveCor  
United States  
miguel@alivecor.com

Paul Kligfield  
Weill Cornell Medicine  
United States  
pkligfield@gmail.com

Frederik Kroon  
Welch Allyn  
United States  
f.kroon@ieee.org

Emerson Liu  
Allegheny Health Network  
United States  
emersonliu@msn.com

Chenguang Liu, Ph.D.  
Philips Healthcare  
US  
chenguang.liu@philips.com

Slawomir Lobodzinski,  
California State University  
USA  
mail@lobodzinski.com

David Lombardi  
Cardioline Spa  
Italia  
d.lombardi@cardioline.it

Robert Lux  
University of Utah  
United States  
robert.lux@utah.edu

Peter Macfarlane, DSc  
University of Glasgow  
Scotland  
peter.macfarlane@glasgow.ac.uk

Rob MacLeod, Ph.D.  
University of Utah  
United States  
maclieod@sci.utah.edu

Deepa Mahajan  
Boston Scientific Corp.  
United States  
deepa.mahajan@bsci.com

Christoph Maier, Ph.D.  
Heilbronn University  
Germany  
christoph.maier@mailbox.org

Sara Mariani, Ph.D.  
Philips Research North America  
USA  
sara.mariani@philips.com

Nicoletta Marzocchi, Ph.D.  
Mortara Instrument Europe  
Italy  
nicoletta.marzocchi@hillrom.com

Jeffery Mitchell, Ph.D.  
Zoll LifeVest  
United States  
jefferymitchell333@gmail.com

Michael Nakagawa  
Philips Healthcare  
US  
mike.nakagawa@philips.com
Patrick Noffke  
Hillrom  
United States  
patrick.noffke@hillrom.com

Beata Ondrusova  
Institute of Measurement Science, Slovak Academy of Sciences  
Slovakia  
umerondb@savba.sk

Olle Pahlm, M.D., Ph.D.  
Lund University  
Sweden  
olle.pahlm@med.lu.se

Saman Parvaneh, Ph.D.  
Edwards Lifesciences  
USA  
saman.parvaneh@gmail.com

Michele Pelter, Ph.D.  
University of California San Francisco  
United States  
michele.pelter@ucsf.edu

Cristina Perez  
University of Zaragoza  
España  
cperez@unizar.es

Erick Andres Perez Alday, Ph.D.  
Emory university  
United States  
erick@dbmi.emory.edu

Aaron Peterson  
HeartSciences  
United States  
aaron.peterson@heartsciences.com

Pyotr Platonov, M.D., Ph.D.  
Lund University  
Sweden  
Pyotr.Platonov@med.lu.se

Sunita Pokhrel Bhattarai  
University of Rochester School of Nursing  
United States  
sunita_pokhrelbhattarai@urmc.rochester.edu

Danila Potyagaylo, Ph.D.  
EPIQure GmbH  
Germany  
danila.potyagaylo@gmail.com

Cadathur Rajagopalan  
Mindray  
United States  
cvrgopalanlink@gmail.com

Fabio Rangoni  
Cardioline Spa  
Italia  
f.rangoni@cardioline.it

Esa Rasanen, DSc  
Tampere University  
Finland  
esa.rasanen@tuni.fi

Antonio Luiz Ribeiro, M.D., Ph.D.  
Universidade Federal de Minas Gerais  
Brazil  
tom1963br@yahoo.com.br

Massimo Rivolta, Ph.D.  
Università degli Studi di Milano  
Italy  
massimo.rivolta@unimi.it

Khaled Rjoob, M.D.  
Ulster University  
United Kingdom  
rjoob-k@ulster.ac.uk

Javier SAIZ-VIVO,  
Medtronic Bakken Research Center  
Netherlands  
javier.saizvivo@medtronic.com
Mintu Turakhia, M.D.  
*Stanford University*  
United States  
mintu@stanford.edu

Peter van Dam, Ph.D.  
*Peacs BV*  
Netherlands  
peter.van.dam@peacs.nl

René van Es  
*University Medical Center Utrecht*  
Nederland  
r.vanes-2@umcutrecht.nl

Niraj Varma, M.D., Ph.D.  
*CCF*  
USA  
varman@ccf.org

Polina Voloshko, M.D.  
*BioTelemetry Inc.*  
United States  
polina.voloshko@gobio.com

John Wang  
*Philips Healthcare*  
United States  
john.j.wang@philips.com

Gang Xu  
*University of Michigan*  
United States  
gaxu@med.umich.edu

Joel Xue, Ph.D.  
*Emory University*  
USA  
joel.q.xue@emory.edu

Brian Young  
*GE Healthcare*  
United States  
brian.young@med.ge.com

Long Yu  
*General Electric*  
USA  
long.yu@ge.com

Elena Zaklyazminskaya, M.D., Ph.D.  
*Petrovsky Research Centre of Surgery*  
Россия  
zhelene@mail.ru

Wojciech Zareba  
*University of Rochester*  
United States  
wojciech.zareba@heart.rochester.edu

Jessica Zegre-Hemsey, Ph.D.  
*University of North Carolina at Chapel Hill*  
United States  
jzhemsey@email.unc.edu

Arthur Zemanek Zemanek  
*University of Rochester*  
United States  
arthur_zemanek@urmc.rochester.edu

Brian Zenger  
*University of Utah*  
USA  
brian.zenger@hsc.utah.edu

Yu-He Zhang  
*Philips Healthcare*  
United States  
yu-he.zhang@philips.com

Sharone Zlochiver  
*Hillrom - Welch Allyn Cardiology*  
United States  
sharon.zlochiver@gmail.com

Wei Zong, Ph.D.  
*Philips Healthcare*  
USA  
wei.zong@philips.com