Characterizing the cardiovascular functions during atrial fibrillation through lumped-parameter modeling

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- In the USA and Europe **7 million people are currently affected by AF** ⇒ incidence is expected to double within the next 40 years;
- AF is responsible for **substantial morbidity** and **mortality** in the general population;
- **Broad interest**: statistical analyses on the heartbeat distributions, risk factors, correlation with other cardiac pathologies.
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Open key aspects

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- The anatomical and structural complexity of some regions (e.g., right ventricle) makes estimates not always feasible and accurate ⇒ **substantial absence of well-established information**;
- **Presence of other pathologies** (hypertension, atrial dilatation, mitral stenosis, ...) ⇒ the specific role of AF is not easily detectable and distinguishable. *Side pathology is cause or effect?*
Motivation and Goal

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- Accurate **statistical analysis** of the cardiovascular dynamics, which is not easily accomplished by in vivo measurements.
Cardiovascular scheme

P: pressure
V: volume
Q: flow rate
C: compliance
E: elastance
L: inductance
R: resistance
Physiologic and fibrillated beating

- **Normal Sinus Rhythm (NSR)**
  - RR extracted from a correlated pink Gaussian distribution;
  - Time varying (right and left) atrial elastance;
  - Full left ventricular contractility;
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Lumped-parameter modeling of atrial fibrillation
Left ventricle

<table>
<thead>
<tr>
<th></th>
<th>NSR</th>
<th>AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO [l/min]</td>
<td>4.80</td>
<td>4.38</td>
</tr>
<tr>
<td>SV [ml]</td>
<td>63.84</td>
<td>47.21</td>
</tr>
<tr>
<td>EF [%]</td>
<td>53.27</td>
<td>37.12</td>
</tr>
<tr>
<td>SW [J]</td>
<td>0.87</td>
<td>0.57</td>
</tr>
</tbody>
</table>
**Arterial pressure: time series and statistics**

- **Hemodynamic parameters**
- **Systemic arterial pressure**
- **Left atrium**
- **Flow rates**

### Results

<table>
<thead>
<tr>
<th>$P_{sas}$ [mmHg]</th>
<th>Mean</th>
<th>Systolic</th>
<th>Diastolic</th>
<th>Pulsatile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NSR</strong></td>
<td>99.52</td>
<td>116.22</td>
<td>83.24</td>
<td>32.99</td>
</tr>
<tr>
<td><strong>AF</strong></td>
<td>89.12</td>
<td>103.66</td>
<td>77.24</td>
<td>26.42</td>
</tr>
</tbody>
</table>

**Pressure and volume behaviour**

- **Hemodynamic parameters**
  - **Systemic arterial pressure**
  - **Left atrium**
  - Flow rates

### Pressure and Volume Behaviour

#### (a) Pressure $P_{la}$ [mmHg]
- **Atrial kick**
- **Rapid growth**
- **Plateau**

#### (b) Volume $V_{la}$ [ml]
- **Atrial kick**
- **Rapid growth**
- **Plateau**

### Table: Left Atrium Volume

<table>
<thead>
<tr>
<th>$V_{la}$ [ml]</th>
<th>Mean</th>
<th>End-Systolic</th>
<th>End-Diastolic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NSR</strong></td>
<td>56.53</td>
<td>64.41</td>
<td>55.37</td>
</tr>
<tr>
<td><strong>AF</strong></td>
<td>65.95</td>
<td>71.41</td>
<td>68.84</td>
</tr>
</tbody>
</table>

S. Scarsoglio, ICMMB 2014

Lumped-parameter modeling of atrial fibrillation
**Left heart: mitral and aortic flows**

- $Q_{mi}$ and $Q_{ao}$: the increased portion of regurgitant flow during short beats is not systematically accompanied by a higher contribute of direct flow $\Rightarrow$ **possible functional mitral regurgitation** and **aortic valve insufficiency**;
Right heart: tricuspid and pulmonary flows

- $Q_{ti}$ and $Q_{po}$: the greater amount of regurgitant flow due to a rapid beat is in large part compensated by a greater amount of direct flow $\Rightarrow$ right valves insufficiency is less likely to occur.
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- Reduced contractility of the right ventricle and the ventricular interaction should be properly accounted for;
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Isolate single cause-effect relations, a thing which is not possible in real medical monitoring:

- the drops of systemic arterial pressure and cardiac output are entirely induced by the reduced ventricular contractility during AF;
- the decrease of the ejection fraction and the LA enlargement are primarily caused by the irregular heart rate;
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**Discussion and Conclusive Remarks**

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- Accurate **statistical description** of the cardiovascular dynamics, a task which is rarely accomplished by in vivo measurements;
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- **Future work:**
  - Response to AF with the combined presence of altered cardiac conditions (e.g., left atrial appendage clamping);
  - Modeling response to real beating series for both NSR and AF.