# Lumped-parameter modeling of the cardiovascular system

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# Cardiovascular scheme

P: pressure

V: volume

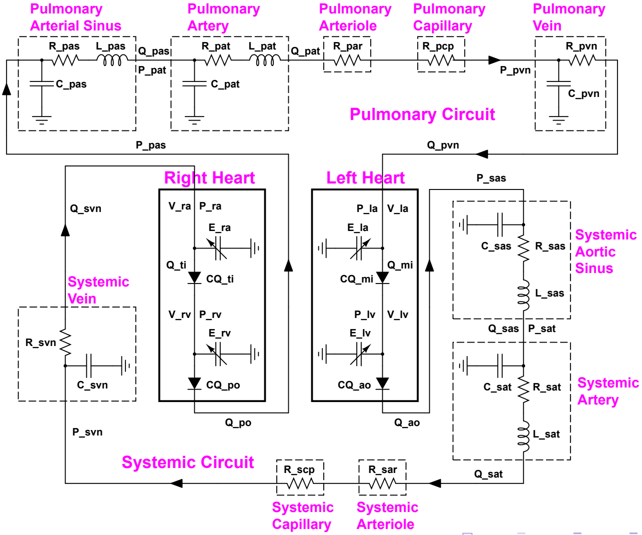
Q: flow rate

C: compliance

E: elastance

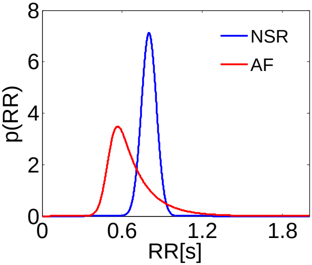
L: inductance

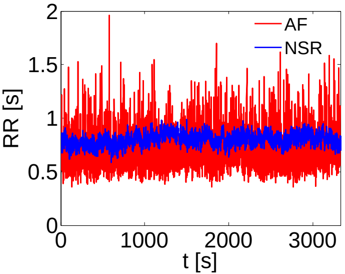
R: resistance



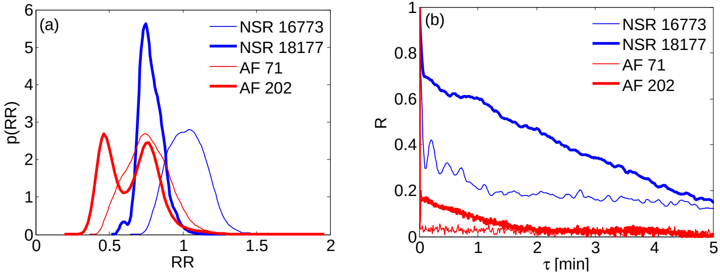
# Reconstructed physiologic and fibrillated beating

- **Normal Sinus Rhythm (NSR)**
  - RR extracted from a correlated pink Gaussian distribution;
  - Time varying (right and left) atrial elastance;
- **Atrial Fibrillation (AF)**
  - RR extracted from an exponentially modified Gaussian distribution;
  - Constant (right and left) atrial elastance $\Rightarrow$ No atrial kick;



# Real RR series (MIT Database)



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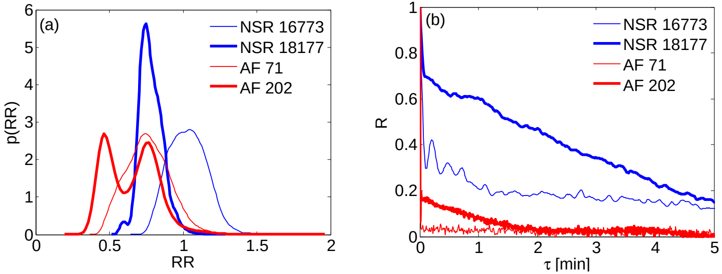
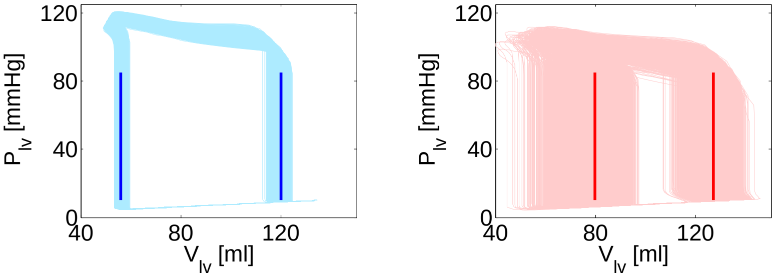



| | $\mu$ [s] | $\sigma$ [s] | $c_v$ | Sex | Age |
|---|---|---|---|---|---|
| NSR 16773 | 1.03 | 0.13 | 0.12 | M | 26 |
| NSR 18177 | 0.78 | 0.08 | 0.10 | F | 26 |
| AF 71 | 0.76 | 0.15 | 0.19 | / | / |
| AF 202 | 0.65 | 0.17 | 0.27 | / | / |

# Left ventricle



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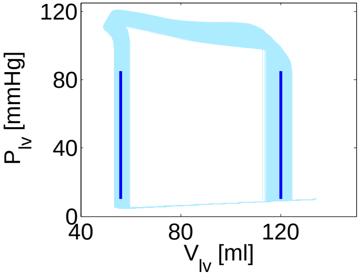
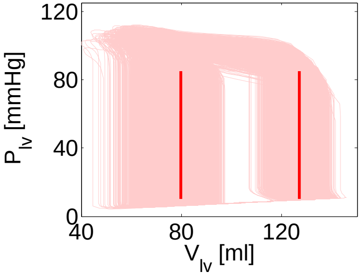
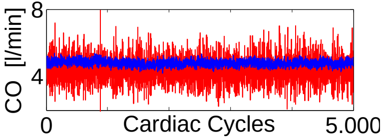
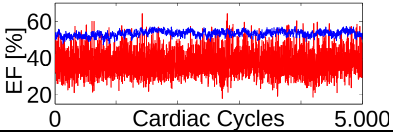


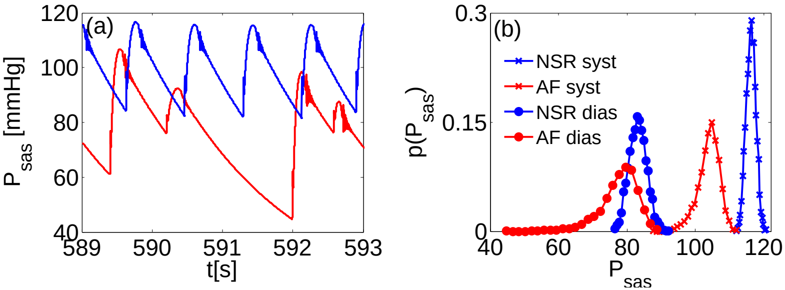




| | NSR | AF |
|---|---|---|
| CO [l/min] | 4.80 | 4.38 |
| SV [ml] | 63.84 | 47.21 |
| EF [%] | 53.27 | 37.12 |
| SW [J] | 0.87 | 0.57 |

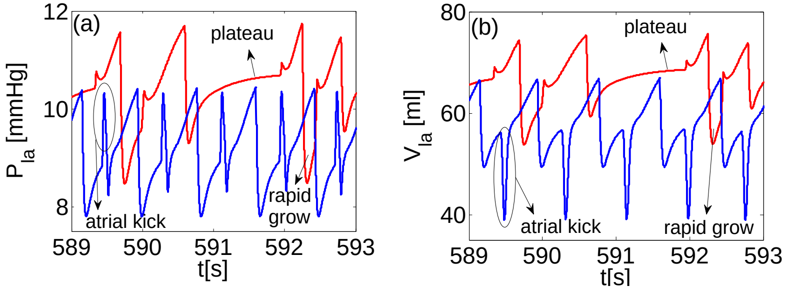
# Arterial pressure: time series and statistics




| $P_{sas}$ [mmHg] | Mean | Systolic | Diastolic | Pulsatile |
|---|---|---|---|---|
| NSR | 99.52 | 116.22 | 83.24 | 32.99 |
| AF | 89.12 | 103.66 | 77.24 | 26.42 |

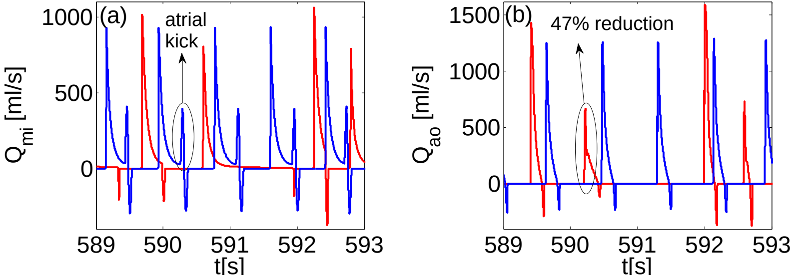
*Scarsoglio, Guala, Camporeale, Ridolfi, Med. Biol. Eng. Comput., 2014.*

# Atrial pressure and volume




| $V_{la}$ [ml] | Mean | End-Systolic | End-Diastolic |
|---|---|---|---|
| NSR | 56.53 | 64.41 | 55.37 |
| AF | 65.95 | 71.41 | 68.84 |

# Mitral and aortic flow rates

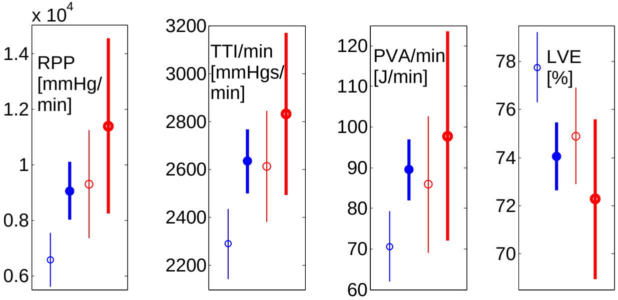



| | NSR | AF |
|---|---|---|
| Mitral RF [%] | 13.59 | 9.94 |
| Aortic RF [%] | 7.62 | 10.91 |

- Different backflow valve openings during AF: Mi ↓, Ao ↑;
- Peak E wave velocity does not correlate with RF.

*Scarsoglio, Camporeale, Guala, Ridolfi, in preparation, 2015.*

# Oxygen Consumption




- Bigger expense for the oxygen consumption (RPP, TTI/min, PVA/min) and decreased left ventricular efficiency (LVE) during AF;
- The major effects of AF are due to HR acceleration, being rhythm changes less impacting.

*Scarsoglio, Med. Eng. & Phys., under review 2015.*

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- Present results should be interpreted as **pure consequences of AF alone** and not induced by other pathologies;
- Accurate **statistical description** of the cardiovascular dynamics, a task which is rarely accomplished by in vivo measurements;
- **New information** on hemodynamic parameters (e.g., flow rates, right ventricle dynamics), difficult to measure and almost never treated in literature.

# Perspectives and future work

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- Combined presence of **other cardiovascular pathologies** (e.g., mitral insufficiency, hypertension, etc);
- Inclusion of the **baroregulation mechanisms**.