

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

Stefania Scarsoglio¹
Andrea Guala² Carlo Camporeale² Luca Ridolfi²

¹Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy

²Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Italy

19th International Conference on Mechanics in Medicine and
Biology

3-5 September 2014, Bologna, Italy



What is atrial fibrillation (AF)

- AF is the **most common arrhythmia** due to the disorganized electrical activity of the atria, causing **irregular and rapid heartbeats**;



What is atrial fibrillation (AF)

- AF is the **most common arrhythmia** due to the disorganized electrical activity of the atria, causing **irregular and rapid heartbeats**;
- **Symptoms**: palpitations, chest discomfort, anxiety, fall in blood pressure, decreased exercise tolerance, pulmonary congestion;



What is atrial fibrillation (AF)

- AF is the **most common arrhythmia** due to the disorganized electrical activity of the atria, causing **irregular and rapid heartbeats**;
- **Symptoms**: palpitations, chest discomfort, anxiety, fall in blood pressure, decreased exercise tolerance, pulmonary congestion;
- **Higher incidence with age**: 2.3% of people older than 40 years are affected, up to more than 8% of people older than 80 years;
- Prevalence is markedly amplifying in industrialized countries;



What is atrial fibrillation (AF)

- AF is the **most common arrhythmia** due to the disorganized electrical activity of the atria, causing **irregular and rapid heartbeats**;
- **Symptoms**: palpitations, chest discomfort, anxiety, fall in blood pressure, decreased exercise tolerance, pulmonary congestion;
- **Higher incidence with age**: 2.3% of people older than 40 years are affected, up to more than 8% of people older than 80 years;
- Prevalence is markedly amplifying in industrialized countries;
- In the USA and Europe **7 million people are currently affected by AF** \Rightarrow incidence is expected to double within the next 40 years;
- AF is responsible for **substantial morbidity** and **mortality** in the general population;



What is atrial fibrillation (AF)

- AF is the **most common arrhythmia** due to the disorganized electrical activity of the atria, causing **irregular and rapid heartbeats**;
- **Symptoms**: palpitations, chest discomfort, anxiety, fall in blood pressure, decreased exercise tolerance, pulmonary congestion;
- **Higher incidence with age**: 2.3% of people older than 40 years are affected, up to more than 8% of people older than 80 years;
- Prevalence is markedly amplifying in industrialized countries;
- In the USA and Europe **7 million people are currently affected by AF** \Rightarrow 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.



Open key aspects

Several key points during AF are still not completely understood from literature data:

- **Pulmonary and systemic arterial pressures:** hypotension, normotension and hypertension seem to be equally probable;



Open key aspects

Several key points during AF are still not completely understood from literature data:

- **Pulmonary and systemic arterial pressures:** hypotension, normotension and hypertension seem to be equally probable;
- **In vivo measures:** (i) difficulty due to the heart rate variability, (ii) necessity of immediate medical treatment;



Open key aspects

Several key points during AF are still not completely understood from literature data:

- **Pulmonary and systemic arterial pressures:** hypotension, normotension and hypertension seem to be equally probable;
- **In vivo measures:** (i) difficulty due to the heart rate variability, (ii) necessity of immediate medical treatment;
- 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;**



Open key aspects

Several key points during AF are still not completely understood from literature data:

- **Pulmonary and systemic arterial pressures:** hypotension, normotension and hypertension seem to be equally probable;
- **In vivo measures:** (i) difficulty due to the heart rate variability, (ii) necessity of immediate medical treatment;
- 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

- Understand and quantify, through a stochastic modeling approach, the **impact of paroxysmal AF on the cardiovascular system** of a healthy young adult (structural remodeling effects neglected);



Motivation and Goal

- Understand and quantify, through a stochastic modeling approach, the **impact of paroxysmal AF on the cardiovascular system** of a healthy young adult (structural remodeling effects neglected);
- AF can be analyzed without other pathologies \Rightarrow **highlight single cause-effect relations**, trying to address from a mechanistic point of view the cardiovascular feedbacks which are currently poorly understood.



Motivation and Goal

- Understand and quantify, through a stochastic modeling approach, the **impact of paroxysmal AF on the cardiovascular system** of a healthy young adult (structural remodeling effects neglected);
- AF can be analyzed without other pathologies \Rightarrow **highlight single cause-effect relations**, trying to address from a mechanistic point of view the cardiovascular feedbacks which are currently poorly understood.
- The main cardiac parameters can all be obtained at the same time, while clinical studies usually focus only on a few of them at a time \Rightarrow **overall good agreement with the clinical state-of-the-art measures**;



Motivation and Goal

- Understand and quantify, through a stochastic modeling approach, the **impact of paroxysmal AF on the cardiovascular system** of a healthy young adult (structural remodeling effects neglected);
- AF can be analyzed without other pathologies \Rightarrow **highlight single cause-effect relations**, trying to address from a mechanistic point of view the cardiovascular feedbacks which are currently poorly understood.
- The main cardiac parameters can all be obtained at the same time, while clinical studies usually focus only on a few of them at a time \Rightarrow **overall good agreement with the clinical state-of-the-art measures**;
- Accurate **statistical analysis** of the cardiovascular dynamics, which is not easily accomplished by in vivo measurements.



Cardiovascular scheme

P: pressure

V: volume

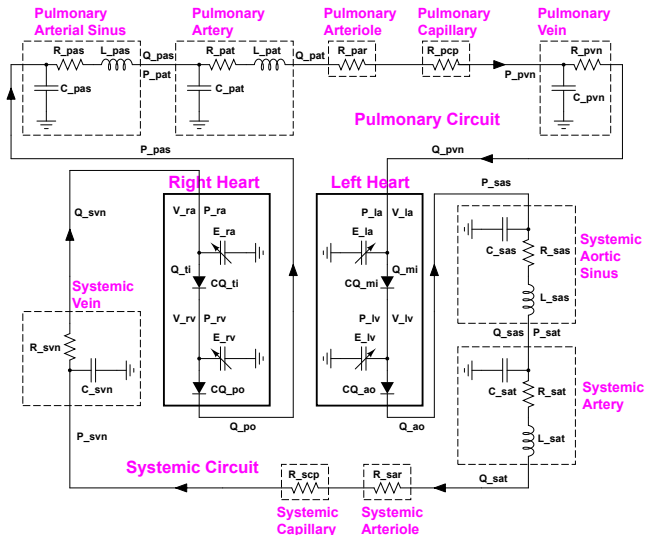
Q: flow rate

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;



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;

- **Atrial Fibrillation (AF)**

- RR extracted from an exponentially modified Gaussian distribution;
- Constant (right and left) atrial elastance;
- Reduced left ventricular contractility;



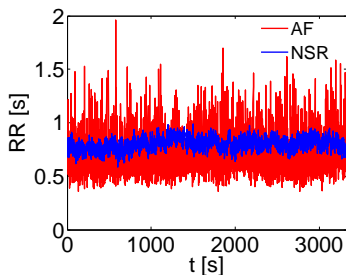
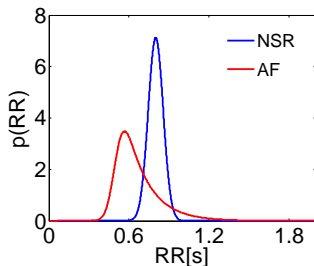
Physiologic and fibrillated beating

- **Normal Sinus Rhythm (NSR)**

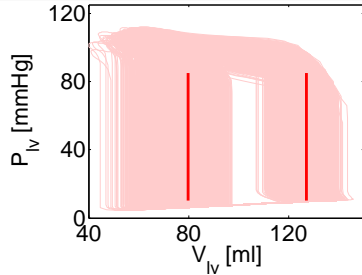
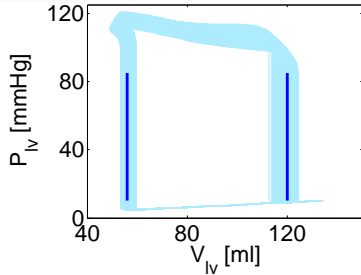
- RR extracted from a correlated pink Gaussian distribution;
- Time varying (right and left) atrial elastance;
- Full left ventricular contractility;

- **Atrial Fibrillation (AF)**

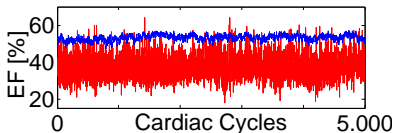
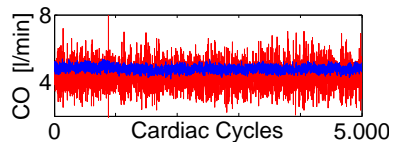
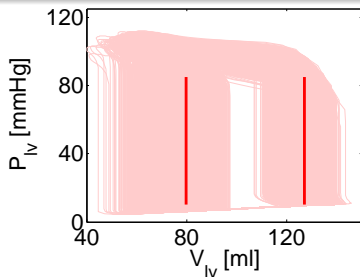
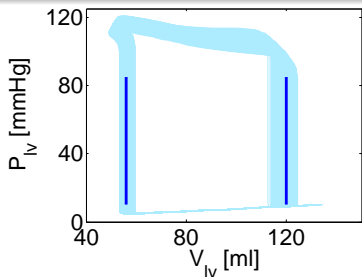
- RR extracted from an exponentially modified Gaussian distribution;
- Constant (right and left) atrial elastance;
- Reduced left ventricular contractility;



Left ventricle



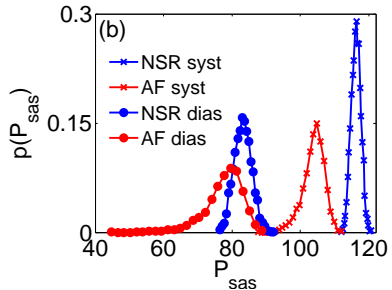
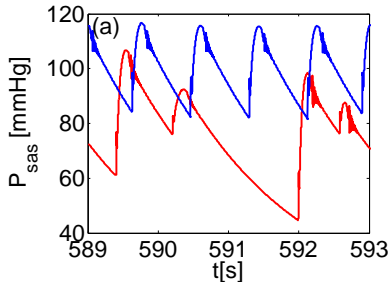
Left ventricle



	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

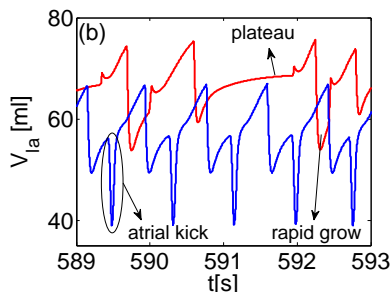
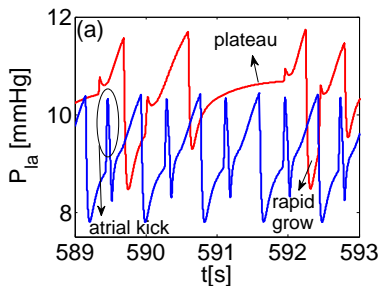


P_{sas} [mmHg]	Mean	Systolic	Diastolic	Pulsatile
NSR	99.52	116.22	83.24	32.99
AF	89.12	103.66	77.24	26.42

Scarsoglio et al., Med. & Biol. Eng. & Comput., 2014 (in press).



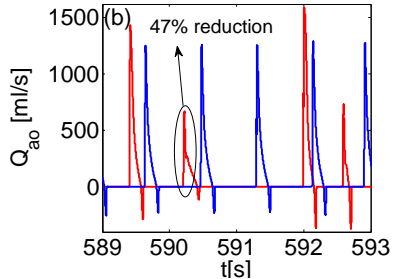
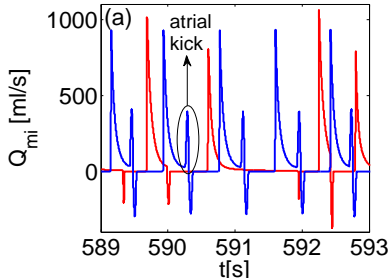
Pressure and volume behaviour



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



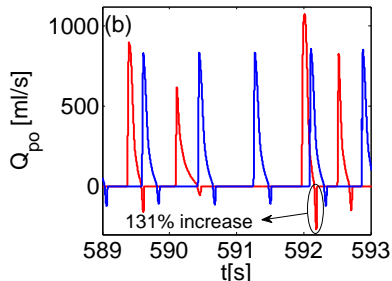
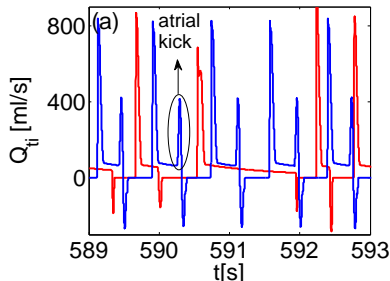
Left heart: mitral and aortic flows



- 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.**



Discussion and Conclusive Remarks

- First attempt to quantify, through a stochastic modeling, the **role of acute AF on the whole cardiovascular system**;



Discussion and Conclusive Remarks

- First attempt to quantify, through a stochastic modeling, the **role of acute AF on the whole cardiovascular system**;
 - Anatomical remodeling due to long-term effects and short-term regulation effects of the baroreceptor mechanism are absent;
 - Reduced contractility of the right ventricle and the ventricular interaction should be properly accounted for;



Discussion and Conclusive Remarks

- First attempt to quantify, through a stochastic modeling, the **role of acute AF on the whole cardiovascular system**;
 - Anatomical remodeling due to long-term effects and short-term regulation effects of the baroreceptor mechanism are absent;
 - Reduced contractility of the right ventricle and the ventricular interaction should be properly accounted for;
- **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;



Discussion and Conclusive Remarks

- **Moderate systemic hypotension and left atrial enlargement** should be interpreted as **pure consequences of AF alone** and not induced by other pathologies;



Discussion and Conclusive Remarks

- **Moderate systemic hypotension** and **left atrial enlargement** 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;



Discussion and Conclusive Remarks

- **Moderate systemic hypotension** and **left atrial enlargement** 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), difficult to measure and almost never treated in literature;



Discussion and Conclusive Remarks

- **Moderate systemic hypotension** and **left atrial enlargement** 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), difficult to measure and almost never treated in literature;
- 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.

