Full details of the proposed research project

Simulation of cardiopulmonary resuscitation strategies in myocardial infarction and asphyxia using an integrated and high fidelity computational model.

Host

Dr Marianna Laviola, Assistant Professor, School of Science, Faculty of Medicine and Health Sciences.

Description of the proposed project

The main of the project is to investigate how different aetiologies of cardiac arrest (CA) can require different cardiopulmonary resuscitation (CPR) strategies in a virtual subject. CA is a sudden state of circulatory failure due to a loss of cardiac function and it can be originated by causes related to the heart (cardiogenic), such as myocardial infarction (MI) or unrelated (non-cardiogenic), such as asphyxia (As) [1]. To attempt resuscitation, the European Resuscitation Council (ERC) recommends administrating standard CPR using a single approach for all adult patients (30:2 compressions/ventilation ratio) with chest compressions delivered at a rate of 100 to 120 compressions/min and depth of >5 cm. [2] However, the discrepancy between what is recommended and the ‘real world’ of CPR has resulted in a near low survival rate from CA in the past years.

Due to the difficulty of conducting clinical trials and due to a poor translation of the results to humans in animal studies, the scientific evidence supporting the full understanding of the pathophysiological state of CA and CPR strategies still suffers from important gaps in knowledge. Computational modelling offers a fresh, new perspective. Virtual models of patients and pathology are amenable to detailed validation, assuring reproducibility and translation into the human application.

The student will use our Interdisciplinary Collaboration in Systems Medicine (ICSM) simulation suite, a set of integrated, high-fidelity cardiopulmonary models, built in a MATLAB ‘superstructure’ developed by our team [3].

Research question and hypothesis.

Should CPR strategies be specific to the aetiology of CA, in particular, if they are cardiogenic (e.g. MI) and non-cardiogenic (e.g. As)?

Reversing the pathology that caused the CA is one of the crucial aspects of successful CPR. We hypothesize that different aetiologies required different CPR to have a successful resuscitation. To answer the research question and verify our hypothesis the following 3 connected aims are outlined:

Aim 1. Simulation of CPR in MI.

Simulation of MI. The student will use a recently developed module, in which MI has been simulated in a virtual subject, by reducing the blood flow to the myocardium by 50%, and by implementing three compensation mechanisms.

Simulation of CPR. The student will use a recently developed thoracic model, which allows simulating CPR, relating the external chest compression force \( F(t) \), applied at the sternum, the intrathoracic tissue pressure \( Pm \), and the pressure on the alveoli \( Pcc \). The \( F(t) \) is expressed as a function of the end compression force \( F_{max} \), compression rate \( CCrate \) and the duty cycle \( Dutycycle \). Additionally, the subject will be mechanically ventilated with a tidal volume of 800 ml at a rate of 10 breaths-min\(^{-1}\).
Protocol. The virtual subject will be configured as in our previous study. [3] After 1 min of spontaneous ventilation (SV), 5 min of MI in SV will be simulated, followed by 5 min of CA. CA will be simulated by setting the heart rate to 0. Additionally, the subject will be apnoeic with the upper airway obstructed. During CPR, apnoea will be maintained, but the upper airway will no longer be obstructed allowing passive ventilation from chest compressions. CPR will be simulated for 5 min following the ERC guidelines (i.e. Fmax =400 N; CCrate 120 cpm; Dutycycle=0.5) [2]

Aim 2. Simulation of CPR in As.

Simulation of As. The student will simulate As-induced CA due to airway obstruction. At the onset of As, the subject will not receive any ventilation (SV with ventilation rate set to 0), and the upper airway will be obstructed.

Protocol. The virtual subject will be configured as in aim 1. After 1 min of SV, 5 min of As will be simulated, followed by 5 min of CA. Similarly to aim 1, CPR will be simulated for 5 min following the ERC guidelines. [2]

Aim 3. Global optimization algorithm to identify the optimal chest compression parameters for each aetiology.

The student will compare the success of resuscitation through surrogate model outputs. To assess the effectiveness of the CPR strategy, the following model outputs have been selected because of their association with the return of spontaneous circulation: end-tidal CO2 (ETCO2), coronary perfusion pressure (CPP) and systolic blood pressure (SBP).

A genetic algorithm (GA) method to solve the optimization problem will be used. The aim of the GA is to find the sets of chest compression parameters (i.e. Fmax, CCrate, Dutycycle) that optimize the CPR model outputs associated with return of spontaneous circulation (i.e., ETCO2, CPP, SBP). Once the GA will be run, the student will compare the CPR strategies and find out whether CPR strategies are specific to the aetiology of CA.


This project would suit a full time student or a student working on a part-time basis over a longer period.

**What overall scientific training will the student receive during the project?**

Dr Laviola will be the primary supervisor providing education in using computational simulation in medicine and training, which will consist of the following:

- Understanding of computational modelling of human systems as a research tool for investigations in the field of CA;
- Understanding how critical the tool of modelling is needed today to enhance modern medical doctor skills;
- Development of computational modelling skills and tools, such as global optimization algorithm, using the software MATLAB;
- Deep knowledge of the pathophysiological state of myocardial infarction and asphyxia and, CPR strategies;
- Acquisition of research skills, i.e. literature search, formulation of research questions, conduction of modelling investigations, interpretation of the results and discussion of the findings;
- Attainment of interdisciplinary research methodology, i.e. research that uses mathematics computer science, medicine and bioengineering;
- Gaining academic presentation and writing skills.

A personal statement from Marianna

"I would love to host a BSV student because research supervision is the most fulfilling part of my job. It combines teaching and research into one and keeps me in the world of students' curiosity. Although I am Assistant Professor, my career as student and PGR ended not so long ago. I have vivid memories of what it means to be a student and their expectations. Furthermore, hosting a BSV student will be an honour for our team, as it is a very prestigious scholarship.

"I strongly believe that joining our interdisciplinary group is a unique opportunity to step into the world of research because it gives the possibility to work with computer science, mathematics and medicine in one single project. This is a fantastic chance especially for those new to research, as the requirements do not need you to familiar with research previously.

"I am confident that at the end of the BSV, the student will become a more independent learner since they will develop their own ideas for the proposed project."

Is there anyone else who will be involved in the supervision of the student for this project?

The undergraduate student will be supervised and trained by Dr Marianna Laviola and will work with MEng Clara Daudre-Vignier. Clara is a third-year PhD student of our Interdisciplinary Collaboration in Systems Medicine (ICSM) team, funded by the National Centre of 3Rs, who is working on the development of the ICSM simulation suite to model cardiac arrest and cardiopulmonary strategies.

Clara will share all the relevant MATLAB codes and provide help for any potential technical and coding questions/issues, acting as a ‘computer/desk’ supervisor.

Furthermore, the student will receive all-encompassing supervision and education from Prof Jonathan G. Hardman, Professor and Head of the group, Consultant in Anaesthesia and Dr Laviola’s line manager.