Cardiac Digital Twins: from Code to Care

R. Barrows (r.barrows23@imperial.ac.uk), C. Augustin, M. Gsell, C. Roney, J.A. Lemus, H. Xu, A. Young, R. Rajani, J. Whitaker, E. Vigmond, M. Bishop, G. Plank, M. Strocchi, S. Niederer

KING'S College LONDON

IMPERIAL

What is atrial fibrillation?

Atrial fibrillation (AF) is a **fast, irregular heart rhythm** caused by chaotic activity in the **upper chambers** of the heart (the atria).

AF in the NHS

AF leads to an increased risk of stroke and heart failure.

More new cases of AF are diagnosed each year than the four most common types of cancer combined.

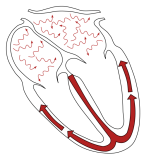
1 in 40

Direct expenditure on AF in the NHS has increased to over £2.2 billion a year.

The AF patient

During AF, the **chaotic electrival activity** in the atria prevents effective pumping of blood and causes a **rapid, irregular heart rate.**

Healthy heart

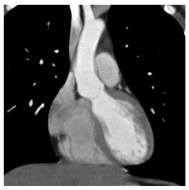


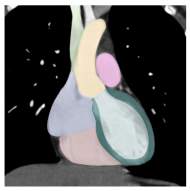
AF heart

Aim

Improve clinical outcomes for AF patients by using **mathematical models of the heart** to find the optimal treatment strategy.

Generating a virtual heart

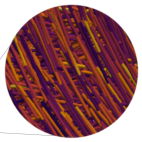


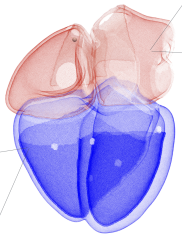


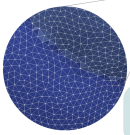
CT scan
(3D medical image)
of patient's heart.

Create a patient-specific anatomical model

The model replicates cell organisation to accurately represent heart muscle.

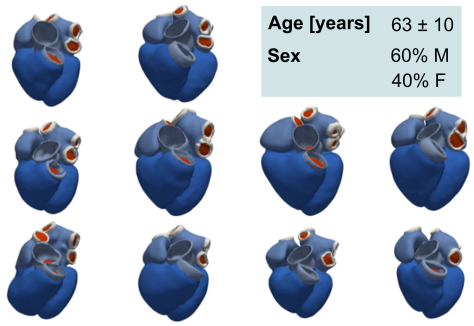






The computational mesh is formed of **~3 million** 3D elements.

A cohort of patient-specific AF heart models



Age [years]	63 ± 10
Sex	60% M 40% F

Calibrating the models ...

To create accurate virtual heart models, we need to calibrate them so they **simulate healthy behaviour correctly**. However, with hundreds of **interacting parameters**, finding the right combination is difficult and would require lots of **trial and error.**

The problem:

Each simulation takes **~5 hours** on a supercomputer.

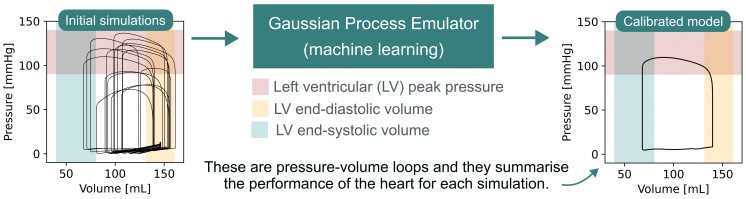
That uses up roughly the same energy as boiling a kettle **100 times** ...

... or driving **70km** in a Tesla!

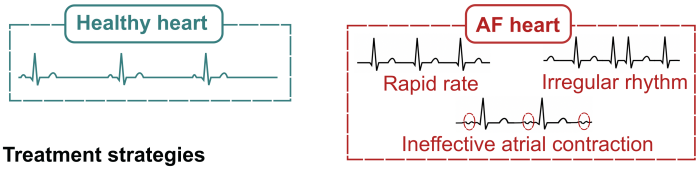
... using machine learning.

The solution:

We can use a powerful and efficient **AI tool** called a **Gaussian Process Emulator**. This is a mathematical model which we train to predict the results of the expensive simulations using relatively few examples.



Treating AF



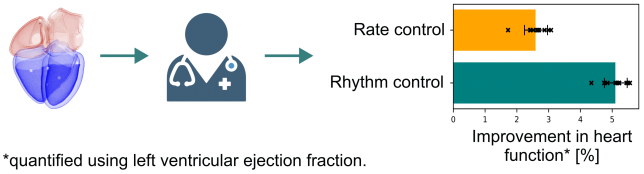
Treatment strategies

Rate control aims to slow the heart rate.

Rhythm control aims to restore normal rhythm and contraction.

Comparing AF Treatment Strategies

We can simulate treatment strategies like rate and rhythm control by **varying the heart rate**, **rhythm** and **atrial contraction** in the models.



*quantified using left ventricular ejection fraction.

What does this mean for the NHS?

Personalised, computational models of the heart allow us to **compare therapies for AF** in specific patients. This paves the way for more **targeted and effective** therapeutic strategies, **improving clinical outcomes** for AF patients and **relieving pressure on the NHS.**