Modelling Solutions to the impact of COVID-19 on Cardiac Waiting Lists

Alan Champneys FIMA (University of Bristol)
Outline

1. Prehistory - a 5-minute history of maths in healthcare
   ▶ the role of the Bristol heart scandal
2. The VKEMS meeting 2-4th Feb 2021
   ▶ dramatis personae
3. Modelling chronic heart failure
   ▶ the problem / the approach
   ▶ what’s happened since
4. Lessons learned
   ▶ data data everywhere – the chronic problem
1. Maths in healthcare - a very biased history

1854 Florence Nightingale
▶ use of data to show effect of preventable disease
▶ improvements in public sanitation
▶ “biggest increase in life expectancy until antibiotics”

1924 Ronald Fisher
▶ design of experiments, significance testing
▶ led to the gold standard in healthcare:
▶ the double-blind control trial
▶ $p$-values rule

2001 David Spiegelhalter FIMA
▶ use of routinely collected data to estimate effect of “health scandals” on life-expectancy
The “Bristol heart scandal” 1995

- harrowing stories of botched heart ops on babies
- or was it a disgruntled anaesthetist?
- boys club culture of “consultant knows best”
- the answer was statistics of messy routinely collected data
- team led by Spiegelhalter report to public enquiry
- 30-35 excess deaths – systemic failures;
- but morbidity? (maybe more like 150 early deaths)
- unprecedented changes to NHS – success data drives improvement
- National Institute for Cardiovascular Outcomes Research (NICOR)
2. VKEMS meeting 2nd-4th Feb 2002

- news stories about COVID-19 causing increased waiting lists
- why not study cancer? — that’s many diseases!
- cardio-vascular disease biggest killer worldwide (WHO)
- ischemic heart disease biggest killer UK men (ONS)
- the NICOR and other data is comprehensive
- we found clinicians who were data-experts
- but how to decide what to do with the data?
- they want to improve patient outcomes!
What happened

- read the report at https://www.vkemsuk.org/publications
- split into the three challenges
  1. the national picture of heart waiting lists
  2. aortic stenosis - a specific procedure
  3. chronic heart disease - a local case study
- this talk will only consider challenge 3
  - although the outcomes of all 3 are now intertwined
Dramatis Personae

The clinicians/data holders Chris Gale (University of Leeds - Professor of Cardiovascular Medicine), Ben Gibbison (University of Bristol - Consultant Senior Lecturer in Cardiac Anaesthesia and Intensive Care), Mamas Mamas (Keele University - Professor of Cardiology), Ramesh Nadarajah (University of Leeds - British Heart Foundation Clinical Research Fellow)

Challenge 1: Jess Enright (University of Glasgow), Feryal Erhun (Cambridge Judge Business School), Rebecca Hoyle (University of Southampton), Pietro Lio (University of Cambridge), Marion Penn (University of Southampton), William Pettersson (University of Glasgow), Yang Zhou (University of Bath)

Challenge 2: Nick Holliman (Newcastle University), Houyuan Jiang (University of Cambridge), Sara Lombardo (Loughborough University), James Rudd (University of Cambridge - Honorary Consultant in Cardiology), Lars Schewe (University of Edinburgh), Kieran Sharkey (University of Liverpool), Matteo Sommacal (Northumbria University), Christian Stickels (University of Liverpool), Jonathan Weir McCall (University of Cambridge - Honorary Consultant in Cardiothoracic Imaging)

Challenge 3: Alan Champneys (University of Bristol), Christine Currie (University of Southampton), Alex Heib (University of Southampton), Lucy Morgan (Lancaster University)

Organisation Matt Butchers (KTN) and Clare Merritt (Newton Gateway to Mathematics)
3. Chronic Heart Failure

Chronic heart failure (CHF) is loosely defined on-going poor heart function leading eventually to death by heart ceasing to pump blood.

Not the same as heart attack – myocardial infarction (MI) – which is clot in blood vessels supplying heart leading to heart tissue death.

Many causes of CHF; age, high blood pressure, MI.

Primary diagnosis is via symptoms - breathlessness, chest pain, leg swell; and ECG + blood test (at GPs)

Secondary diagnosis; echocardiogram ultrasound image

About half have LV ejection volume $< 40\%$ – only these are really treatable

four roughly-defined clinical stages

in stage four 80% have other underlying conditions

early diagnosis key to longer life expectancy

Median life expectancy post diagnosis is 5 years.

Estimated 650K currently diagnosed in UK (maybe 950K total)
Disease progression

3 stages of treatment

1. primary (GP) ECG, lifestyle, generic drugs
2. secondary (hospital) – Echocardiogram, powerful drugs, mild intervention
3. tertiay (specialist hospital - rare) - transplant, pacemaker etc.
Summary of data on effect of Covid-19

Main hypothesis:
- Data from Leeds & National March-Nov 2020 shows effect first lockdown. Second lockdown will have similar cumulative effect.

Primary care
- Number of ECGs down to 66% of pre-pandemic levels.
- Data from one hospital shows GP referrals down 80%

Secondary care
- Echocardiogram waiting list up by 150%
- Both acute and referred CHF hospital admissions down 50%
- But cardiology waiting list similar pre- and post- pandemic (!!?)

Mortality and end of life care
- 2.2K more deaths with CHF (only 10% from CHF) during
- Deaths in community up, in hospital down
- Without medication, life expectancy decreases by about 50%
Main ideas for building a mathematical model

1. Use data from steady state to parametrise a patient flow model
2. use the perturbation from the pandemic to model different volumes of patients in the system at different disease states
3. then run the model to see what happens in first wave – use data from Leeds
4. put an optimisation wrapper around the model so that we can run what-if scenarios.
5. we start with a discrete event simulation (DES) approach
6. later incorporate into a systems dynamics model
7. work with NHS Improve to turn into decision support tool at trust level.
Conceptual DES model

No CHF status
- Symptoms? [N] → N

Living with CHF
- Y → Q

GP
- Y → Check up
- Y → Further treatment needed? [N] → Q
- Y → N

Hospital
- Echo received
- Diagnosed? [Y] → Q
- Needs surgery? [N] → Receives implant
- Y → Q
- Y → Q
- Q → Q
- Q → Q

Receives Medication
- N

Receives Implant
- N

Receives Surgery
Including disease state modification

- Untreatable CHF
- No CHF
  - Mild CHF
    - Mild CHF on medication
  - Mild CHF on medication
  - CHF living with implant and on medication
  - CHF living with implant and on medication
  - Severe CHF on medication (palliative care)
  - Severe CHF on medication (palliative care)

Death is possible from all stages but at different rates
Results so far – detailed data from Leeds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distribution/Model</th>
<th>Base Value/ Covariates</th>
<th>Source</th>
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<tbody>
<tr>
<td>Patient Arrival</td>
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<td>BHF</td>
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<td>Age</td>
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<td>NHS</td>
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<td>GP Path</td>
<td>Linear</td>
<td>Age</td>
<td>NHS</td>
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<td>NT-proBNP Result</td>
<td>Cox P-H</td>
<td>Age, NT-proBNP Result</td>
<td>NHS</td>
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<td>Time to see GP</td>
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<td>Hospital Path</td>
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<tr>
<td>Time to hospital admission</td>
<td>Cox P-H</td>
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<tr>
<td>Death</td>
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<tr>
<td>Time to Death</td>
<td>Cox P-H</td>
<td>Age, NT-proBNP Result</td>
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<td>Echocardiogram</td>
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<td>Echo appointment time</td>
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<td>NHS Direct</td>
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<td>NHS</td>
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<td>Covid</td>
<td>Gamma</td>
<td>Gamma(2, 14)</td>
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<td>Lockdown delay to see GP</td>
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<td>NHS</td>
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<td>Inpatient echos per day</td>
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<td>Lockdown 1 end</td>
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<td>25-09-2020</td>
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<td>Leeds restrictions start</td>
<td></td>
<td>12-04-2021</td>
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Results so far – echocardiogram waiting lists

Alan Wise (Lancaster) & Alex Heib (Southampton) & Ramesh Nadrajah (Leeds), Lucy Morgan (Lancaster) & Christine Currie (Southampton)

Figure 3: Average number in GP and Hospital queues from Jan 2020 - December 2021 with 90% CIs.
Next steps/ ongoing work

1. include disease progression in model
   ▶ blood test results as proxy for disease state on entering hospital
   ▶ model flow through treatment pathways
   ▶ estimate disease progression
   ▶ model change in life expectancy of each patient

2. run “what if scenarios” prioritising different patients/treatments

3. decide on utility/optimisation function:
   ▶ maximise Quality Adjusted Life Years (QALY) — unethical
   ▶ treat sickest first — equally unethical
   ▶ minimise \( \sum_{i=1}^{4} \alpha_i P_i \),
     where \( P_i \) is number of patients on waiting list of urgency level \( i \)

4. longer term goals
   ▶ hire postdoc to work with NHS improve to incorporate into patient flow model.
   ▶ create simple decision-support tool to make available to NHS trusts
   ▶ improve patient lives!
4. Lessons learned

Chronic heart disease is a good case study for maths and healthcare
- it is a complex (group of) degenerative condition(s) affecting 2% of UK
- current primary-secondary-tertiary care pathways are complex
- Covid-19 has not affected waiting lists in a simple way

The wave is coming.
- biggest build up is those not entering primary stage
- bottleneck at diagnosis – echocardiogram
- cardiology referred patients are in more severe disease state than before

We are building a patient flow model and parametrising it
- using detailed data from Leeds
- thinking of the pandemic as a perturbation
- a more general process-based approach to treatment optimisation?

There is talk of a data revolution in healthcare
- using routinely collected data to optimise treatment & patient flow
- Collaboration is the key! — all kinds of maths, data science + domain experts.