Emergency hospital admissions for the elderly: insights from the Devon Predictive Model

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ABSTRACT

Background In the UK, people aged 85 and over are the fastest growing population group and are predicted to double in number by 2030. Emergency hospital admissions are also rising.

Methods All emergency admissions for the registered population in Devon to all English hospitals were analysed by age, and admission rates per thousand registered were calculated. The Devon Predictive Model (DPM) was built, using local data, to predict emergency admissions in the following 12 months. This model was compared with the Combined Predictive Model over five risk categories.

Results The registered Devon population on 31 March 2011 was 761,652 with 65,892 emergency admissions in 2010/2011. The DPM had 89 variables including several local factors which strengthened the model. Three of the four most powerful predictors were age 85–89, 90–94 and 95 and over. The positive predictive value for the DPM was better than the CPM’s in all five risk categories. Half (49.6%) of all emergency admissions were from those aged 65 or over. Admissions rose progressively and significantly in each successive elderly age band. At age 85 and over there were 420 emergency admissions per thousand registered.

Conclusions Age, especially 85 and over, has been undervalued as a risk factor for emergency hospital admissions.

Keywords Age, Age85plus, emergency care, hospitals, predictive-modelling

Introduction

Ageing of the population is a big challenge to the National Health Service (NHS) and other western health systems. Demographic predictions are reliable as the people concerned already exist. The elderly can be usefully considered in sub-groups: age 65–74, 75–79, 80–84 and 85 and over. Of these, the 85 and over sub-group matters particularly as they are the fastest growing sub-group in the UK population,1 are the frailest people and are predicted to double in number in England between 2010 and 2030.2

Emergency admissions to hospital nationally are causing concern for four reasons. First, they are unpleasant and frightening to older people who, in Devon, face a 23% probability of death within 6 months of them.3 Secondly, emergency admissions disrupt local community services.

Thirdly, emergency admissions form $\sim$35% of all admissions to NHS hospitals and disrupt elective work. Finally, emergency admissions to hospital are expensive to the NHS, costing an average of £1883 in Devon (NHS Devon, personal communication, 2012).

The Public Sector Agreement (2006)4 planned to reduce emergency bed days by 5% by 2008 and has stimulated the construction of predictive models to identify people most
likely to experience emergency admissions. It is hoped that if patients at high risk can be found, then case management designed to reduce some emergency admissions will be effective. Some authors have called for better referenced polices for reducing admissions. In the literature, there are many different predictive models; some focus on readmissions, while others are based on hospital-derived data only. Some authors emphasize the advantages of using national data sets as these provide attractively large numbers, whilst others link admissions and readmissions.

There are advantages in using NHS data to predict emergency admissions. First, the NHS is unusual internationally in not requiring patients to pay on receipt of care; the poorest person can consult a health professional without payment or insurance. Secondly, in the region where the model was developed, the NHS covers 98% of the population. Thirdly, the extrapolation of Kaiser data in the USA to the UK has been questioned.

Many factors affect emergency hospital admissions. The best response to multiple variables is to build a regression model, including them all and then use the model to determine which variables have the greatest influence on emergency admissions. The leading national model is the Combined Predictive Model (CPM). One of us (T.C.), with colleagues in NHS Devon (Primary Care Trust) built a new model, the Devon Predictive Model (DPM). This was designed to explore factors influencing all emergency admissions for people registered with general practices in Devon, emphasizing local factors.

Devon is a good area to examine the influence of ageing on hospital admissions since it currently has 22.9% of the population aged 65 and over, and 3.3% of the population aged 85 and over. These figures closely match the predicted age structure of the population for England in 2035. Devon therefore models likely patterns of care for England in the future.

We aimed to (i) explore the relationship between the age of the registered population and the rate of emergency admissions to hospital, especially the effect of age of 85 and over; (ii) build a model to predict emergency admissions in Devon using local factors and (iii) compare the accuracy of the predictions of the new model (DPM) with those of the existing model (CPM).

Methods
Registered population
The registration of all patients with general practices in Devon is recorded in NHS Devon. Emergency admissions to hospitals are all known as NHS Primary Care Trusts (PCTs) pay the claims for them made by hospitals. The NHS system provides NHS Devon with information about all admissions for Devon registered people throughout England.

Age on admission to hospital
The elderly registered population at 31 March 2011 was analysed first in two age groups—those aged 65–84 and those aged 85 and over. Secondly, sub-categories of the elderly were identified (age 65–74, 75–79, 80–84 and 85 and over).

Emergency admissions were analysed by the age of the patient over 4 consecutive years (from 1 April 2007 to 31 March 2011). Rates of admission per thousand registered people in each age group were calculated. Secondly, using just the first quarter of each of the four years, we tested whether there was a statistically significant age-related trend in admissions, using $\chi^2$ tests for trend.

Building the devon predictive model
The study population was obtained via a download from the NHS Connecting for Health Spine Portal for 31 July 2010. Following the method used by the CPM, data on inpatient stay, outpatient attendance and accident and emergency attendance from the NHS Secondary Uses Service database were downloaded. To construct a locally sensitive model, these data were combined with general practice data extracted, with permission, from Devon general practices via a combination of MIQUEST queries and third-party extracts, and placed within secure PCT databases.

All 69 variables from the CPM were combined with local variables derived from the literature, from GPs and commissioners, and from local health data. For example, duration of GP registration was added to test if continuity of GP care influences hospital admissions. All long-term condition variables used Read codes from the general practice data.

The outcome used was an emergency hospital admission in the follow-up year (1 August 2010 to 31 July 2011), meaning an unplanned admission to hospital or an emergency re-admission. Admissions for the population to all district, teaching and community hospitals across England were included. The proportion of admissions to local hospitals (defined as those within 50 miles of Exeter) was also determined.

Using the same method as the CPM, data for the 2 years from 1 August 2008 to 31 July 2010 were used to derive the independent variables. All variables were encoded using Structured Query Language queries to interrogate the...
secure databases and were transformed into binary format indicating the presence or absence of the condition/status in any patient. Previous iterations of the model showed that instability can occur when variables with low prevalence are included, regardless of statistical significance. Therefore, variables involving fewer than 100 patients were excluded.

An exploratory multivariate linear regression was performed using the remaining variables to test for multicollinearity using the Variance Inflation Factor (VIF) provided by the SPSS® Version 17.0 statistical software. Variables with a VIF over 2.5 sometimes cause concern but no VIF exceeded 2.0. As in the CPM,14 several variables were tested for specific interactions.

The remaining variables were entered as categorical variables in binary logistic regressions with a standard default cut-off probability of 0.5. With many variables being tested, only those significant at the 5% level in the exploratory model were selected. The variables in the final model were ranked on beta coefficients to identify the most influential. The final model was evaluated as usual by calculating discrimination, using the area under the receiver operating characteristic curve (C-statistic), and the overall model positive predictive value (PPV), specificity and sensitivity for various cut-offs of the predictive risk score.

To validate the model and avoid over-fitting, the whole sample of patients at 31 July 2010 was randomly split into an 80% derivation (training) set and a 20% validation set. The logistic regression was run over the two samples to test for stability as defined by >2% change in model metrics between the two sets.

Finally, patient probabilities for every patient were transformed into a number between 0 and 100 (100 indicating highest risk) to provide a ranked list of patient risk scores, thus identifying people at highest risk of emergency admission.

**Feedback to general practices**

The DPM was designed as a case-finding algorithm. Therefore, details of individual patients predicted to be in the top 5% highest risk of emergency admission were fed back to the patients’ general practices for consideration for case management.

**Comparison of DPM with CPM**

To compare the two models, both algorithms (DPM and CPM) were run on the Devon population simultaneously. The PPVs of the highest ranking sub-groups were calculated, using the same cut-offs for both models, i.e. the top 200, 1000, 3800, 7000 and 16000 patients ranked by each model as having the highest risk of admission.

### Results

#### Population

A download from NHS Connecting for Health yielded data for 722,383 patients registered with all 105 general practices in Devon at 1 July 2010. These patients formed the study population. Their characteristics are summarized in Table 1. General practice data were received from 102/105 (97%) of all Devon practices.

NHS Devon’s records showed that 761,652 patients were registered with Devon GPs on 31 March 2011. Of these, 142,162 (18.7%) patients were aged 65–84 and 25,401 (3.3%) patients were aged 85 and over.

The registered population in Devon grew from 746,666 on 31 March 2007 to 761,652 on 31 March 2011 (an increase of 14,986; 2.0%). Similarly, in the same time period, the age 65–84 population grew from 131,327 to 142,162 (an increase of 10,835; 8.3%), while the 85 and over population grew from 23,663 to 25,401 (an increase of 1738; 7.3%).

### Table 1 Population characteristics at 31 July 2010

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n = 722,383)</th>
<th>People experiencing emergency admissions (n = 40,143)</th>
<th>People not experiencing emergency admission (n = 682,240)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–24 years</td>
<td>26.7</td>
<td>18.3</td>
<td>27.2</td>
</tr>
<tr>
<td>25–44 years</td>
<td>22.8</td>
<td>14.1</td>
<td>23.3</td>
</tr>
<tr>
<td>45–64 years</td>
<td>28.6</td>
<td>21.0</td>
<td>29.1</td>
</tr>
<tr>
<td>65–84 years</td>
<td>18.8</td>
<td>33.1</td>
<td>18.0</td>
</tr>
<tr>
<td>85 years and over</td>
<td>3.1</td>
<td>13.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Gender, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>48.9</td>
<td>47.2</td>
<td>49.0</td>
</tr>
<tr>
<td>Female</td>
<td>51.1</td>
<td>52.8</td>
<td>51.0</td>
</tr>
<tr>
<td>Hospital use in previous 2 years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous emergency admission, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>8.9</td>
<td>30.9</td>
<td>7.6</td>
</tr>
<tr>
<td>No</td>
<td>91.1</td>
<td>69.1</td>
<td>92.4</td>
</tr>
</tbody>
</table>

*People experiencing emergency admissions in the year 1 August 2010 to 31 July 2011.

*Age, gender and previous admission analyses conducted at 31 July 2010.
Emergency admissions to hospital
Between 1 April 2010 and 31 March 2011, there were 65,892 emergency admissions and only 4.3% were not to local hospitals.

Between the financial years 2007/08 and 2010/11, emergency admissions rose year on year (Table 2) for the whole registered population—an absolute increase of 6841 admissions (11.6%).

Emergency admissions and older age
One-third (33.4%; 22,016/65,892) of all emergency admissions in Devon during 2010–2011 arose from the age 65–84 population and 16.2% (10,660/65,892) from the age 85 and over population. Therefore, 49.6% of all emergency admissions were for the over 65s.

Over the 4 years studied (Table 2), the emergency admissions for the 65–84-year old population rose by 4571 [16.3%; $\chi^2$ for linear trend $= 37.42$ (df 1); $P$, 0.0001], and for the age 85 and over population by 1780 [20.1%; $\chi^2$ for linear trend $= 109.30$ (df 1); $P$, 0.0001].

In 2010–11, the rate of emergency admission for the 85 and over age group was 420 per thousand registered patients per year.

Within the over-65 age group, the number and rate of emergency admissions rose incrementally across increasing age bands (Table 3). This trend was statistically significant ($\chi^2$ for linear trend $= 2843.14$ (df 1); $P$, 0.0001).

The model
The final DPM included 89 variables (see Supplementary data, Table S1) and was stable. The most predictive variable was ‘age 90–94’ ($\beta = 1.321$, $P$, 0.001), the second highest was ‘age 95-plus’ ($\beta = 1.195$, $P$, 0.001), with ‘age 85–89’ ($\beta = 1.047$, $P$, 0.001) the fourth most highly predictive variable. Being aged 85 and over was therefore revealed as being particularly important.

Several local variables were significant predictors in the final model; for example, a shorter length of registration with the GP was associated with an increased risk of emergency admission ($\beta = 0.319$, $P$, 0.001).

At a risk score threshold of 50, the sensitivity of the DPM was 8.4%, the specificity 99.6% and the PPV 54.6%. The C-statistic was 0.781 (95% confidence intervals $= 0.778$ to 0.783).

Comparison of the predictive performance of the CPM and the DPM
In each of the five highest at-risk sub-groups, the DPM produced significantly higher PPVs than the CPM (Table 4). For example, for the 200 patients at highest risk (0.03% of the population), the PPV of the DPM was 86.5% and the PPV of the CPM was 71.5%. For the 3800 patients at highest risk (0.5% of the population), the PPV using the DPM was 59.0% and the PPV using the CPM was 48.5%.

Discussion
Main findings
The DPM, in a population with 3.3% aged 85 and over, revealed the substantial influence of old age on emergency admission to local hospitals. In Devon, half (49.5%) of all emergency admissions in 2011 were for people aged 65 and over and, among people aged 85 and over, there were 420 emergency admissions per thousand registered patients in a single year.

Table 2 Emergency admission to hospital by year and age group (2007–11)

<table>
<thead>
<tr>
<th>Yeara</th>
<th>All ages</th>
<th>Aged 65–84 years</th>
<th>Aged 85 years and over</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of emergency admissionsb</td>
<td>Rate per 1000</td>
<td>Number of emergency admissionsb</td>
</tr>
<tr>
<td>2007/08</td>
<td>59,051</td>
<td>78.2</td>
<td>19,225</td>
</tr>
<tr>
<td>2008/09</td>
<td>62,383</td>
<td>82.3</td>
<td>20,039</td>
</tr>
<tr>
<td>2009/10</td>
<td>64,029</td>
<td>83.9</td>
<td>20,633</td>
</tr>
<tr>
<td>2010/11</td>
<td>65,892</td>
<td>86.5</td>
<td>22,016</td>
</tr>
</tbody>
</table>

aData for Quarter 4, 2010–11.

Table 3 Quarterly emergency admissions to hospital in the elderly (age ≥65 years) by increasing age bands (2010–11)

<table>
<thead>
<tr>
<th>Age band (years)</th>
<th>Number of patients in age banda</th>
<th>Number of emergency admissionsb</th>
<th>Emergency admission rate per 1000 in age banda,b</th>
</tr>
</thead>
<tbody>
<tr>
<td>65–69</td>
<td>48,362</td>
<td>1172</td>
<td>24</td>
</tr>
<tr>
<td>70–74</td>
<td>37,784</td>
<td>1223</td>
<td>32</td>
</tr>
<tr>
<td>75–79</td>
<td>31,166</td>
<td>1502</td>
<td>48</td>
</tr>
<tr>
<td>80–84</td>
<td>24,850</td>
<td>1757</td>
<td>70</td>
</tr>
<tr>
<td>85 and over</td>
<td>25,401</td>
<td>2808</td>
<td>111</td>
</tr>
<tr>
<td>All age bands</td>
<td>167,563</td>
<td>8462</td>
<td>51</td>
</tr>
</tbody>
</table>

aData for Quarter 4, 2010–11.

b$\chi^2$ for linear trend $= 2843.14$ (df 1); $P$, 0.0001.
The DPM significantly outperformed the CPM in all the five risk categories. Of the 200 people in the group predicted by the DPM to be most at risk of emergency admission, 143 (86%) were subsequently admitted—30 more emergency admissions correctly predicted than by the CPM.

A new finding was that 95.7% of all emergency admissions were to local hospitals. They reflect local decisions, for local people with local age structures, using local resources, and local work patterns. Local data reflect these; hence it is logical for the DPM to incorporate them.

Strength of the findings
NHS Devon is one of the largest PCTs in England. Further strengths are that the number of admissions is accurate as hospitals are incentivized to claim. New use of local data (e.g. duration of registration with the GP) strengthened the model.

What is already known on this topic?
Over the last decade, the Department of Health commissioned a package of predictive case-finding models. Two of these used inpatient data on prior hospitalizations to identify patients at the highest risk of re-admission (PARR1 and PARR2).6,9

The CPM14 combined data from secondary care with data from GP records. When compared with PARR2, the more-inclusive CPM improved the accuracy of predicting admissions for ‘very high risk’ patients and enabled the prediction of hospital admission for patients across the risk continuum, including those with no recent history of inpatient admission.14 Thus, the CPM allowed for risk stratification at levels that may be more amenable to case management, identifying individuals at risk of emergency admission before they experience repeated admissions.

The PEONY Model18 developed in NHS Tayside, Scotland, sought to predict emergency admissions in all individuals aged 40 years and above. Using a risk score cut-off of 50, the PPV of that model was 67.1%. As in our study, age was highlighted as one of the strongest predictors of admission.

Asthana and Gibson19 have argued that age has been undervalued as a determinant of need. Salisbury et al.20 showed that age is strongly associated with multi-morbidity (45% of people have two or more chronic conditions by the age of 75), and that multi-morbidity drives health service use.

Clinical Commissioning Groups are now exploring predictive models. Identifying high-risk groups is a crucial part of these models.6,21 When limited resources are available, case-finding of those at the highest risk of admission becomes the objective and the performance of models on the bulk of the population becomes less relevant. The purpose is to aid case management which implies developing an effective intervention. This is being tested in Devon and we hope to report on that separately. It will of course never be possible to prevent all emergency admissions.

What this study adds
In this study, emergency admissions were about twice as numerous amongst 65–84 year olds and four to five times more common amongst the 85 and over age group than for the population generally. Emergency admissions for the whole population, for the 65–84-year old group, and for the 85 and over group all rose significantly between 2009 and 2011.

Table 4 PPVs for the CPM and DPM for patients predicted at the highest risk of emergency admission

<table>
<thead>
<tr>
<th>'At-risk' sub-group</th>
<th>Number (%) patients in 'at-risk' group predicted by the model who had an emergency admission within 12 months</th>
<th>Combined predictive model (CPM)</th>
<th>Devon predictive model (DPM)</th>
<th>Statistical testa</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 top-ranked patients (0.03% of registered population)</td>
<td>143/200 (71.5%)</td>
<td>173/200 (86.5%)</td>
<td>$\chi^2 = 13.56$ (df 1); $P &lt; 0.001$</td>
<td></td>
</tr>
<tr>
<td>1000 top-ranked patients (0.13% of registered population)</td>
<td>605/1000 (60.5%)</td>
<td>733/1000 (73.3%)</td>
<td>$\chi^2 = 36.99$ (df 1); $P &lt; 0.001$</td>
<td></td>
</tr>
<tr>
<td>3800 top-ranked patients (0.5% of registered population)</td>
<td>1843/3800 (48.5%)</td>
<td>2241/3800 (59.0%)</td>
<td>$\chi^2 = 83.84$ (df 1); $P &lt; 0.001$</td>
<td></td>
</tr>
<tr>
<td>7000 top-ranked patients (0.92% of registered population)</td>
<td>2639/7000 (37.7%)</td>
<td>3708/7000 (53.0%)</td>
<td>$\chi^2 = 329.37$ (df 1); $P &lt; 0.001$</td>
<td></td>
</tr>
<tr>
<td>16000 top-ranked patients (2.1% of registered population)</td>
<td>4896/16000 (30.6%)</td>
<td>6877/16000 (43.0%)</td>
<td>$\chi^2 = 527.35$ (df 1); $P &lt; 0.001$</td>
<td></td>
</tr>
</tbody>
</table>

aThe DPM was more accurate in prediction in each of the five ‘at-risk’ categories when these are analysed separately ($\chi^2$ tests). However, the categories are not independent, since those in the top 200 are by definition in each of the other four ‘at-risk’ sub-groups as well.
Age 85 and over emerged in the DPM as the major predictor of emergency hospital admission. Whilst it has long been known that older people have high admission rates, never before has it been shown that, in a population like Devon’s (where 3.3% of the whole population is already aged 85 and over), as many as 420 per thousand population experience an emergency admission within 1 year.

The importance of local factors

Emergency admissions in Wales are 40% more per head of population than in England22 and, within England, there is a 3-fold variation between areas.23,24

When individuals aged 85 and over are relatively rare they are seen as exceptions. However, a recent report suggests that this age group will double in size between 2010 and 2030.2 Once they are as numerous as every 30th person, as in Devon today, then local general practices and services adapt to them. Hence, their admissions are best studied where they are most numerous.

The CPM was designed as a generalizable national model, and used mixed data from different PCTs, whereas the DPM unlocks the power of local knowledge. The method used for building the model can be generalized to other areas, but then relevant local data should be used.

These findings have considerable implications, since emergency admissions cost NHS Devon £1883 each in 2011 (Personal communication, NHS Devon, 2012). An ageing population is confidently predicted for England.25,26 Devon’s current over-65 population (22.9%) is close to the Office for National Statistics (ONS) projections for the over-65 population for England in 2032 (22.1%).1 Devon’s population today models England’s tomorrow.

The implications are great as the ONS predicts the age 85 and over population in England will grow to 3.5 million (increase of 2.1 million people) by 2035, when they will then form 5% of the whole population.3 There are substantial limitations in extrapolating nationally, but at the current rate of 420 emergency admissions per thousand in the age 85 and over population in Devon, national emergency admissions in this age group alone in 2035 would number 1.47 million with consequential pressure on services and costs. This would greatly challenge the NHS.

For a single general practice in Devon, nearly 60% of emergency admissions were predicted out of the top-ranked 3800 patients by the DPM. This figure (5 per thousand of the registered population) is a feasible number of patients for a single practice to case manage. Across Devon, in this top 0.5% risk category, the DPM identified an additional 398 patients (10%) admitted within a year when compared with the CPM.

Limitations of this study

The limitations were that: all patients were from a single county, limiting generalizability of the variables. There was potential for coding inaccuracies in clinical records,27 and we could not capture emergency admissions for people visiting Devon. The DPM did not separate readmissions. Extrapolating regional data nationally has inevitable limitations.

In conclusion, the DPM using local factors has revealed that age 85 and over is the single most important factor predicting emergency admission to hospital. In Devon in 2010–11, there were 420 emergency admissions per thousand registered population in this age group.

Supplementary data

Supplementary data are available at PUBMED online.

Ethics committee approval

A research ethics committee opinion was not required for this study. The Devon Predictive Model was constructed within NHS Devon as part of a local service evaluation and development exercise, based on the Combined Predictive Model. Participating practices gave consent to the extraction of data from the records of their registered patients (except where patients had previously opted-out of data sharing arrangements), and this process was approved by the Caldicott Guardian for NHS Devon.

Authors’ contributions

T.C. built and tested the model at NHS Devon, interpreted the data, contributed to the preparation of data tables, produced the figures, contributed to the drafting of the manuscript and commented on later versions of the manuscript. T.C. is acting as guarantor of the data. D.P.G. conceived the idea for the article, interpreted the data, contributed to the preparation of data tables and statistical analysis, contributed to the development of the local model, wrote the early drafts of the manuscript, and commented on later versions of the manuscript. J.F. contributed to the interpretation of the data, preparation of data tables and statistical analysis, contributed to the development of the local model, wrote the early drafts of the manuscript, and commented on later versions of the manuscript. C.W. undertook data analysis; contributed to the preparation of data tables and data interpretation; contributed to the drafting and editing of the manuscript and commented on later versions of the manuscript. P.E. reviewed the literature, interpreted the data, contributed to the preparation of data tables and statistical analysis, contributed to the
drafting and editing of the manuscript, and commented on later versions of the manuscript.

Acknowledgements

The Devon Predictive Model was developed by a team at NHS Devon: within that team Mr Kelvin Graham, Ms Shirley McLean and Mr Peter Turnbull provided valuable direction, advice and support to the lead author (TC). Dr Paul Lovell (East Street Surgery, South Molton, Devon) also provided valuable advice and support. Dr Peter Langley (St Leonard’s Practice, Exeter) provided editorial advice in relation to the preparation of this article. We received valuable statistical advice from Professor Stephen Brooks of the University of Exeter and Select Statistical Services (www.select-statistics.co.uk). The development team received hospital data from the NHS Secondary Uses Service and are grateful to all organizations which contributed local data.

Funding

No external funding was received. No payment has been received from a pharmaceutical company or other agency to write this article.

Conflicts of interest

The authors declare that (i) T.C. developed the Devon Predictive Model for NHS Devon and is an employee of that organization; (ii) T.C. is also a Director of a private consultancy, GnosisLogica Limited, which advises on predictive modelling; (iii) St Leonard’s Practice is a general practice within NHS Devon and has received funding for research in the past from NHS Devon; (iv) T.C., D.J.P.G., J.F., C.W. and PHE, and their spouses, partners or children, have no other financial relationships or non-financial interests that may be relevant to the submitted work.

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