Completion of annual diabetes care processes and mortality: A cohort study using the National Diabetes Audit for England and Wales

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Funding Information
British Heart Foundation, Grant/Award Number: RE/18/6/34217; Diabetes UK; NHS England and NHS Improvement; South Asian Health Foundation

Abstract
Aim: To conduct an analysis to assess whether the completion of recommended diabetes care processes (glycated haemoglobin [HbA1c], creatinine, cholesterol, blood pressure, body mass index [BMI], smoking habit, urinary albumin, retinal and foot examinations) at least annually is associated with mortality.

Materials and methods: A cohort from the National Diabetes Audit of England and Wales comprising 179 105 people with type 1 and 1 397 790 people with type 2 diabetes, aged 17 to 99 years on January 1, 2009, diagnosed before
January 1, 2009 and alive on April 1, 2013 was followed to December 31, 2019. Cox proportional hazards models adjusting for demographic characteristics, smoking, HbA1c, blood pressure, serum cholesterol, BMI, duration of diagnosis, estimated glomerular filtration rate, prior myocardial infarction, stroke, heart failure, respiratory disease and cancer, were used to investigate whether care processes recorded January 1, 2009 to March 31, 2010 were associated with subsequent mortality.

Results: Over a mean follow-up of 7.5 and 7.0 years there were 26,915 and 388,093 deaths in people with type 1 and type 2 diabetes, respectively. Completion of five or fewer, compared to eight, care processes (retinal screening not included as data were not reliable) had a mortality hazard ratio (HR) of 1.37 (95% confidence interval [CI] 1.28-1.46) in people with type 1 and 1.32 (95% CI 1.30-1.35) in people with type 2 diabetes. The HR was higher for respiratory disease deaths and lower in South Asian ethnic groups.

Conclusions: People with diabetes who have fewer routine care processes have higher mortality. Further research is required into whether different approaches to care might improve outcomes for this high-risk group.

Keywords: cohort study, type 1 diabetes, type 2 diabetes

1 | INTRODUCTION

Optimal management of blood glucose, lipids and blood pressure reduces the microvascular and macrovascular complications of diabetes.\(^1^-^3\) Accordingly, measurement and management of glycated haemoglobin (HbA1c), blood pressure and lipid profile are at the centre of national and international diabetes care guidelines.\(^4^-^7\) Regular review of these and other risk factors for complications, including weight and smoking habit, are recommended, as are tests for early detection of kidney, foot and eye disease.

In England, the National Institute for Health and Care Excellence (NICE) recommends that people with type 1 diabetes\(^4\) and type 2 diabetes\(^5\) are offered nine annual processes (measurement of HbA1c, lipids, creatinine, albuminuria, blood pressure and body mass index [BMI], ascertainment of smoking status, and examination of the feet and retinae), and the completion of these has been incentivized in primary care.\(^8\) Most international guidelines also stress the importance of these care processes. However, whilst their regular completion might seem intuitively sensible, the level of evidence to support the guideline-recommended processes, including their effect on clinical outcomes, is usually not known or is rated at the lowest standard of evidence (“expert consensus” or “clinical experience”).\(^7\)

In England and Wales, the National Diabetes Audit (NDA) collects patient-level data on people with diagnosed diabetes. The present study assesses whether recorded care processes completion was associated with mortality over the subsequent decade after adjustment for the risk factors that the care processes uncover, individual demographic characteristics and comorbidities.

2 | MATERIALS AND METHODS

2.1 | Data sources

The NDA has collated data on people with diagnosed diabetes registered with a primary or specialist healthcare provider in England since 2003. Individuals receiving care from general practice and specialist outpatient services based in acute and community trusts are included if they have a valid code for diabetes mellitus (excluding gestational diabetes) in their electronic health record.\(^9\) The 2009/2010 NDA data collection included data from 6700 (76%) general practices and was estimated to include data on 81.1% people aged 17 years and older with diagnosed diabetes in England and Wales.\(^10\)

These data were linked to Hospital Episode Statistics and the Patient Episode Database for Wales, which records all hospital admissions in England and Wales, respectively, and to civil death registrations in both countries collated by the Office for National Statistics.

The legal basis for the NDA data collection and linkage is a “direction” from NHS England to NHS Digital according to section 254 of the Health and Social Care Act for England 2012; in Wales it is granted under section 270 of the Health and Social Care Act. To protect confidentiality, all data with a final digit of 1, 2, 8 or 9 are...
rounded to 0, and 3, 4, 6 or 7 are rounded to 5. Numbers with a final digit of 0 or 5 are unchanged.

2.2 | Study population and observation period

The study population was people aged between 17 and 99 years on January 1, 2009, diagnosed with type 1 diabetes and type 2 diabetes before January 1, 2009 who were included in the 2009/2010 NDA data collection and still alive on April 1, 2013. Analysis was restricted to individuals who survived 3 years after the exposure period to reduce potential bias from the clinically appropriate suspension of diabetes care processes for people in end-of-life care. Individuals were followed up from April 1, 2013 until death or December 31, 2019.

2.3 | Outcomes

The outcomes were death from all causes and underlying (primary) cause of death from cardiovascular disease (International Classification of Disease [ICD]-10 codes I01-I99), cancer (ICD-10 codes C01-C99), respiratory disease (ICD-10 codes J01-J99), diabetes-specific causes (ICD-10 codes E10-14) and renal disease (ICD-10 codes N17-19).

2.4 | Exposures

Data secondarily recorded in general practice systems for retinal examinations for this period are not considered reliable. The primary exposure was, therefore, the number out of a total of eight care processes (blood tests for HbA1c, cholesterol, creatinine, measurement of blood pressure, BMI, albuminuria, smoking habit assessment and the examination of feet) recorded as undertaken between January 1, 2009 and March 31, 2010. As initial exploratory analysis identified that only a minority of people had five or fewer care processes recorded and that people receiving six or seven care processes had similar characteristics and outcomes, these categories were used in the analysis. People who had all eight care processes recorded formed the primary reference group to reflect current national guidelines.

Age and duration of diagnosed diabetes at baseline were calculated using date of birth and date of diagnosis, respectively. Ethnicity was based on self-reported ethnic group as recorded by healthcare providers and classified as White, Mixed, South Asian, Black, other or missing. Type of diabetes was attributed based on the most recent type recorded by a healthcare provider and notified to the NDA. Data from a specialist healthcare provider were assigned precedence over the type of diabetes in the primary care health record.

Deprivation was measured using the area-based Index of Multiple Deprivation 200711 based on the home postcode recorded in the 2009/2010 NDA data collection and split into quintiles for analysis.

The latest reported risk factor measurements in the period January 1, 2009 to March 31, 2010 for HbA1c, systolic blood pressure, total cholesterol, creatinine, BMI and smoking habit were identified. Estimated glomerular filtration rate (eGFR) was calculated using the Modification of Diet in Renal Disease formula.12

Hospital admissions for myocardial infarction (ICD-10 codes I21-22), stroke (ICD-10 codes I61, I63-64, I67.9), heart failure (ICD-10 codes I50), respiratory disease (ICD-10 codes J01-J99) and cancer (ICD-10 codes C01-C99) between January 1, 2004 and December 31, 2008 were identified.

2.5 | Statistical methods

The differences in mean age, duration of diagnosed diabetes, HbA1c and BMI by the number of care processes recorded as undertaken were tested using analysis of variance (ANOVA), with Levene’s test to identify differences in variance. Differences in the proportion of people recorded as receiving care processes for categorical variables (sex, social deprivation, ethnicity, smoking habit) were tested using the chi-squared statistic. Crude mortality rates and mortality rates per 1000 person-years, standardized for age and sex to the European Standard population, were calculated with 95% confidence intervals (CIs) using Byar’s method.13

Cox proportional hazard models were created to assess the associations between the number of recorded care processes and mortality for people with type 1 and people with type 2 diabetes. A series of models was created consisting of sequentially more covariates to examine potential confounding factors.

Separate models, adjusting for all risk factors, were created for mortality from cardiovascular disease, cancer, respiratory disease, diabetes-specific causes and renal failure for type 1 diabetes and type 2 diabetes separately. Models adjusted for all risk factors and stratified by sex, age (less than 65 years old and 65 years and older), ethnic group, quintile of deprivation and whether or not the individual had an acute hospital admission in the year prior to the exposure period were constructed for all-cause mortality in people with type 1 diabetes and in people with type 2 diabetes.

Two models (one for type 1 diabetes and one for type 2 diabetes) adjusted for age, sex, ethnic group, deprivation and whether or not each of the eight care processes had been completed were created to identify if the association with all-cause mortality varied by type of care process. All variables were defined as categorical variables and included a category for missing data. A sensitivity analysis was undertaken in which everyone included in the 2009/2010 NDA and still alive on January 1, 2011 to explore whether the survival bias introduced by excluding deaths shortly after the exposure period altered the findings.

Statistical analysis was undertaken in SAS Enterprise Guide 7.1.

3 | RESULTS

A total of 179 105 people with type 1 diabetes and 1 397 790 with type 2 diabetes were followed up for a mean (SD) of 7.5 (1.4) and 7.0 (1.8) years, respectively. Among those with type 1 diabetes, 80 635 (45.0%) had received all eight care processes at least once between January 1, 2009 and March 31, 2010. 61 230 (34.2%) had received six or seven care...
### TABLE 1  Baseline characteristics by number of care processes received and type of diabetes

|                  | Type 1 diabetes |                  | Type 2 diabetes |                  |
|------------------|-----------------|------------------|-----------------|------------------|
|                  | ≤5 care processes | 6-7 care processes | 8 care processes | ≤5 care processes | 6-7 care processes | 8 care processes |
| Number           | 37 235          | 61 230           | 80 635          | 132 125          | 387 060           | 878 605          |
| Mean (SD) follow up, years | 7.6 (1.32)          | 7.5 (1.38)    | 7.4 (1.48)          | 6.9 (2)           | 7 (1.9)           | 7.1 (1.8)          |
| Sex              |                 |                 |                 |                  |                  |                  |
| Female           | 16 105          | 27 610          | 45.1            | 34 555           | 42.9             | 60 700           | 45.9            | 181 170          | 46.8             | 384 930          | 43.8             |
| Male             | 21 130          | 33 620          | 54.9            | 46 080           | 57.1             | 71 425           | 54.1            | 205 890          | 53.2             | 493 675          | 56.2             |
| Age              |                 |                 |                 |                  |                  |                  |
| <40 years        | 19 710          | 22 750          | 37.2            | 21 595           | 26.8             | 10 655           | 8.1             | 15 695           | 4.1              | 22 685           | 2.6              |
| 40-49 years      | 8050            | 14 465          | 23.6            | 17 300           | 21.5             | 21 915           | 16.6            | 46 300           | 12.0             | 81 125           | 9.2              |
| 50-59 years      | 4675            | 10 840          | 17.7            | 15 785           | 19.6             | 30 390           | 23.0            | 85 015           | 22.0             | 176 495          | 20.1             |
| 60-69 years      | 2700            | 7 660           | 12.5            | 14 385           | 17.8             | 30 500           | 23.1            | 108 930          | 28.1             | 268 360          | 30.5             |
| 70-79 years      | 1485            | 4 300           | 7.0             | 9305             | 11.5             | 24 140           | 18.3            | 94 170           | 24.3             | 247 015          | 28.1             |
| ≥80 years        | 620             | 1 1210          | 2.0             | 2 260            | 2.8              | 14 525           | 11.0            | 36 955           | 9.5              | 82 925           | 9.4              |
| Mean (SD)        |                 |                 |                 |                  |                  |                  |
| Age, years       | 40.6 (16)       | 46.3 (16.2)     | 51 (14.4)       | 60.9 (14.8)      | 63.5 (12.9)      | 65 (11.9)        |
| Sex              |                 |                 |                 |                  |                  |                  |
| Deprivation      |                 |                 |                 |                  |                  |                  |
| Most deprived    | 7770            | 11 625          | 19.6            | 16 475           | 21.1             | 33 345           | 26.1            | 88 140           | 23.5             | 198 075          | 23.4             |
| Second most deprived | 7510          | 11 755          | 19.8            | 15 540           | 19.9             | 28 720           | 22.4            | 78 635           | 20.9             | 176 765          | 20.9             |
| Third most deprived | 7270          | 11 915          | 20.1            | 16 075           | 20.6             | 25 220           | 19.7            | 75 255           | 20.0             | 172 680          | 20.4             |
| Least deprived   | 6915            | 12 035          | 20.3            | 15 375           | 19.7             | 21 645           | 16.9            | 70 110           | 18.7             | 158 250          | 18.7             |
| Missing          | 6620            | 12 070          | 20.3            | 14 760           | 18.9             | 19 040           | 14.9            | 63 540           | 16.9             | 139 585          | 16.5             |
| Ethnic group     |                 |                 |                 |                  |                  |                  |
| White            | 30 000          | 50 365          | 89.6            | 65 885           | 87.9             | 83 910           | 73.3            | 265 790          | 79.1             | 627 640          | 80.8             |
| Mixed            | 340             | 430             | 0.8             | 630              | 0.8              | 1 635            | 1.4             | 3200             | 1.0              | 6520             | 0.8              |
| South Asian      | 1430            | 2515            | 4.5             | 3985             | 5.3              | 15 235           | 13.3            | 37 715           | 11.2             | 78 585           | 10.1             |
| Black            | 1020            | 1530            | 2.7             | 2670             | 3.6              | 7165             | 6.3             | 14 525           | 4.3              | 32 580           | 4.2              |
| Other            | 875             | 1345            | 2.4             | 1820             | 2.4              | 6590             | 5.8             | 14 865           | 4.4              | 31 220           | 4.0              |
| Missing          | 3565            | 5040            | 5645            | 17 590           | 102 060          |                  |

(Continues)
| Smoking status | Type 1 diabetes | Type 2 diabetes |
|----------------|----------------|----------------|
|                | ≤ 5 care processes | 6-7 care processes | 8 care processes | ≤ 5 care processes | 6-7 care processes | 8 care processes |
| Current smoker | 5335            | 32.9            | 12 120        | 25.2            | 15 725        | 19.9            | 12 820            | 26.8            | 50 060        | 17.4            | 120 035        | 13.7            |
| Ex-smoker      | 3165            | 19.5            | 11 450        | 23.8            | 22 180        | 28.0            | 14 255            | 29.8            | 98 530        | 34.3            | 333 940        | 38.1            |
| Nonsmoker      | 470             | 2.9             | 14 15        | 2.9             | 23 50        | 3.0             | 14 450            | 3.0             | 68 60        | 2.4             | 17 750        | 2.0             |
| Never smoked   | 7250            | 44.7            | 23 045        | 48.0            | 38 895        | 49.1            | 19 340            | 40.4            | 132 215       | 46.0            | 404 100        | 46.1            |
| Missing        | 21 020          | 13 205          | 1480          | 84 270          | 99 400        | 2775            |

| Duration       | Type 1 diabetes | Type 2 diabetes |
|----------------|----------------|----------------|
|                | ≤ 5 care processes | 6-7 care processes | 8 care processes | ≤ 5 care processes | 6-7 care processes | 8 care processes |
| < 1 year       | 1215            | 3.3             | 1575          | 2.6             | 2165          | 2.7             | 13 370            | 10.1            | 39 385        | 10.2            | 89 805         | 10.2            |
| 1-2 years      | 2755            | 7.4             | 3655          | 6.0             | 4845          | 6.0             | 24 890            | 18.8            | 72 640        | 18.8            | 167 735        | 19.1            |
| 3-5 years      | 2920            | 7.8             | 4220          | 6.9             | 5590          | 6.9             | 23 500            | 17.8            | 69 535        | 18.0            | 159 015        | 18.1            |
| 5-9 years      | 8350            | 22.4            | 12 470        | 20.4            | 16 310        | 20.2            | 40 390            | 30.6            | 122 070       | 31.5            | 277 675        | 31.6            |
| 10-14 years    | 6325            | 17.0            | 10 025        | 16.4            | 13 310        | 16.5            | 15 725            | 11.9            | 46 635        | 12.0            | 104 610        | 11.9            |
| 15-19 years    | 5150            | 13.8            | 8765          | 14.3            | 11 005        | 13.6            | 7670              | 5.8             | 21 880        | 5.7             | 47 480         | 5.4             |
| ≥ 20 years     | 10 520          | 28.3            | 20 515        | 33.5            | 27 410        | 34.0            | 6585              | 5.0             | 14 920        | 3.9             | 32 280         | 3.7             |

| Duration, years| Type 1 diabetes | Type 2 diabetes |
|----------------|----------------|----------------|
|                | Mean (SD)      | Mean (SD)      |
| < 1 year       | 16.1 (17.4)    | 17.5 (15.7)    |
| 1-2 years      | 17.8 (16.5)    | 8.7 (19.7)     |
| 3-5 years      | 18.8 (17.3)    | 7.5 (13.2)     |
| 5-9 years      | 12.0 (13.3)    | 7.4 (13.3)     |

| HbA1c          | Type 1 diabetes | Type 2 diabetes |
|----------------|----------------|----------------|
| <48 mmol/mol   | 1365           | 8.5            | 4545          | 7.7             | 6715          | 8.5             | 13 600            | 27.0            | 100 765       | 27.3            | 239 035        | 27.6            |
| 48-53 mmol/mol | 1270           | 7.9            | 5155          | 8.8             | 8395          | 10.6            | 8330              | 16.5            | 78 880        | 21.4            | 206 900        | 23.9            |
| 54-58 mmol/mol | 1705           | 10.6           | 69 25         | 11.8            | 10 425        | 13.1            | 6430              | 12.8            | 54 750        | 14.8            | 137 880        | 15.9            |
| 59-74 mmol/mol | 5785           | 36.1           | 22 735        | 38.6            | 31 185        | 39.3            | 11 505            | 22.8            | 81 915        | 22.2            | 186 265        | 21.5            |
| 75-85 mmol/mol | 2585           | 16.1           | 9305          | 15.8            | 11 620        | 14.7            | 4215              | 8.4             | 23 955        | 6.5             | 46 945         | 5.4             |
| ≥86 mmol/mol   | 3325           | 20.7           | 10 205        | 17.3            | 10 980        | 13.8            | 6315              | 12.5            | 29 095        | 7.9             | 47 900         | 5.5             |
| Missing        | 21 205         | 2365           | 1317          | 81 730          | 17 700        | 13 680          |

| HbA1c, mmol/mol| Type 1 diabetes | Type 2 diabetes |
|----------------|----------------|----------------|
| <48 mmol/mol   | 72 (20.2)      | 70.3 (18.6)    |
| 48-53 mmol/mol | 68.1 (17.3)    | 61.5 (20.1)    |
| 54-58 mmol/mol | 58.4 (17.1)    | 56.8 (15.2)    |

| BMI            | Type 1 diabetes | Type 2 diabetes |
|----------------|----------------|----------------|
| <20 kg/m²      | 855            | 5.9            | 2050          | 3.6             | 2345          | 2.9             | 680              | 1.8             | 3905          | 1.1             | 7990           | 0.9             |
| 20-24.9 kg/m²  | 5105           | 35.5           | 16 965        | 29.7            | 21 860        | 27.3            | 5100             | 13.3            | 46 370        | 12.9            | 114 065        | 13.1            |
| 25-29.9 kg/m²  | 4910           | 34.1           | 21 240        | 37.2            | 30 120        | 37.6            | 11 425           | 29.8            | 118 935       | 33.2            | 304 275        | 34.9            |
TABLE 1  (Continued)

|                     | Type 1 diabetes | Type 2 diabetes |                     |                     |                     |                     |
|---------------------|----------------|----------------|---------------------|---------------------|---------------------|---------------------|
|                     | ≤5 care processes | 6-7 care processes | 8 care processes | ≤5 care processes | 6-7 care processes | 8 care processes |
| 30-34.9 kg/m²       | 2260            | 15.7           | 10 775             | 18.9               | 16 550             | 20.6               |
| 35-39.9 kg/m²       | 790             | 5.5            | 3 930              | 6.9                | 6230               | 7.8                |
| ≥40 kg/m²           | 475             | 3.3            | 2 150              | 3.8                | 3 075              | 3.8                |
| Missing             | 22 840          | 4215           | 453                | 93 825             | 28 515             | 5530               |
| BMI, kg/m²          | 26.9 (5.8)      | 27.8 (5.8)     | 28.2 (5.7)         | 31.8 (7.3)         | 31.2 (6.6)         | 30.9 (6.2)         |
| Systolic blood pressure |                |                |                     |                     |                     |                     |
| <120 mm Hg          | 5290            | 25.7           | 13 550             | 22.4               | 16 170             | 20.1               |
| 120-129 mm Hg       | 5025            | 24.4           | 14 915             | 24.7               | 19 560             | 24.3               |
| 130-139 mm Hg       | 4905            | 23.8           | 15 695             | 26.0               | 22 270             | 27.7               |
| ≥140 mm Hg          | 5395            | 26.2           | 16 285             | 26.9               | 22 525             | 28.0               |
| Missing             | 16 625          | 790            | 105                | 61 145             | 3695               | 1035               |
| Cholesterol         |                |                |                     |                     |                     |                     |
| <5 mmol/L           | 6605            | 66.4           | 40 465             | 71.0               | 60 935             | 75.7               |
| ≥5 mmol/L           | 3345            | 33.6           | 16 525             | 29.0               | 19 545             | 24.3               |
| Missing             | 27 285          | 4240           | 155                | 85 840             | 14 615             | 1445               |
| eGFR                |                |                |                     |                     |                     |                     |
| ≥90 mL/min per 1.73 m² | 5445           | 45.7           | 25 340             | 44.1               | 31 945             | 40.0               |
| 60-89 mL/min per 1.73 m² | 4650           | 39.1           | 24 385             | 42.4               | 35 280             | 44.2               |
| 45-59 mL/min per 1.73 m² | 925            | 7.8            | 4470               | 7.8                | 7975               | 10.0               |
| 30-44 mL/min per 1.73 m² | 480            | 4.0            | 2045               | 3.6                | 3410               | 4.3                |
| 15-29 mL/min per 1.73 m² | 220            | 1.8            | 795                | 1.4                | 1045               | 1.3                |
| <15 mL/min per 1.73 m² | 190            | 1.6            | 445                | 0.8                | 250                | 0.3                |
| Missing             | 25 335          | 3750           | 725                | 79 655             | 14 640             | 1255               |
| Prior hospital admission |                |                |                     |                     |                     |                     |
| Myocardial infarction | 340           | 0.9            | 785                | 1.3                | 1 285              | 1.6                |
| Stroke              | 355             | 0.9            | 595                | 1.0                | 810                | 1.0                |
| Heart failure       | 420             | 1.1            | 850                | 1.4                | 1 315              | 1.6                |
| Respiratory disease | 4245            | 11.4           | 6615               | 10.8               | 8575               | 10.6               |
| Cancer              | 450             | 1.2            | 1040               | 1.7                | 1895               | 2.4                |

Abbreviation: BMI, body mass index.
|                | ≤5 care processes                                                                 | Age and sex standardized rate per 1000 person-years (95% CI) | 6-7 care processes                                                                 | Age and sex standardized rate per 1000 person-years (95% CI) | 8 care processes                                                                                                                                 |
|----------------|----------------------------------------------------------------------------------|-------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| N              | Crude rate per 1000 person-years (95% CI)                                        | N                                                           | Crude rate per 1000 person-years (95% CI)                                        | N                                                           | Crude rate per 1000 person-years (95% CI)                                                                                      |
|                | Age and sex standardized rate per 1000 person-years (95% CI)                     | N                                                           | Crude rate per 1000 person-years (95% CI)                                        | N                                                           | Age and sex standardized rate per 1000 person-years (95% CI)                                                                  |
|                |                                                                                   | N                                                           |                                                                                 | N                                                           |                                                                                                                                  |
| Type 1 diabetes| All causes                                                                        |                                                              |                                                                                 |                                                              |                                                                                                                                  |
|                | 4512                                                                               | 16 (15.5-16.5)                                              | 33.5 (32.3-34.8)                                                                | 8660 18.8 (18.4-19.2)                                       | 34.4 (33-35.9)                                                                                                                   |
|                | 2922                                                                               | 6.3 (6.1-6.6)                                               | 11.2 (10.4-12)                                                                 | 4808 8 (7.8-8.3)                                            | 10 (9.4-10.5)                                                                                                                   |
|                | 26                                                                                 | 0.09 (0.06-0.14)                                            | 0.2 (0.1-0.3)                                                                  | 58 0.1 (0.07-0.13)                                          | 0.1 (0.1-0.2)                                                                                                                   |
|                | 1371                                                                               | 3 (2.8-3.1)                                                 | 4.7 (4.3-5.1)                                                                  | 2518 4.2 (4.4-4.4)                                          | 4.7 (4.5-4.9)                                                                                                                   |
|                | 452                                                                               | 1.6 (1.5-1.8)                                              | 4.1 (3.6-4.5)                                                                  | 1602 2.7 (2.5-2.8)                                          | 3.9 (3.5-4.4)                                                                                                                   |
|                | 107 006                                                                            | 39.3 (39-39.5)                                              | 27.5 (27.2-27.7)                                                               | 243 501 39.2 (39-39.4)                                      | 25.2 (25-25.4)                                                                                                                   |
| Cardiovascular disease | 1503                                                                               | 5.3 (5.1-5.6)                                              | 11.1 (10.5-11.8)                                                               | 4808 8 (7.8-8.3)                                            | 10 (9.4-10.5)                                                                                                                   |
| Diabetes specific causes | 765                                                                                 | 2.7 (2.5-2.9)                                              | 4.6 (4.1-5)                                                                    | 1709 2.9 (2.7-3)                                            | 4 (3.5-4.4)                                                                                                                   |
| Renal failure  | 26                                                                                 | 0.09 (0.06-0.14)                                            | 0.2 (0.1-0.3)                                                                  | 59 0.1 (0.07-0.13)                                          | 0.1 (0.1-0.2)                                                                                                                   |
| Cancer         | 570                                                                               | 2 (1.9-2.2)                                                 | 4.4 (4-4.9)                                                                    | 2518 4.2 (4.4-4.4)                                          | 4.7 (4.5-4.9)                                                                                                                   |
| Respiratory disease | 452                                                                               | 1.6 (1.5-1.8)                                              | 4.1 (3.6-4.5)                                                                  | 1602 2.7 (2.5-2.8)                                          | 3.9 (3.5-4.4)                                                                                                                   |
| Type 2 diabetes| All causes                                                                        |                                                              |                                                                                 |                                                              |                                                                                                                                  |
|                | 37 586                                                                             | 41 (40.6-41.4)                                              | 30.8 (30.4-31.1)                                                               | 243 501 39.2 (39-39.4)                                      | 25.2 (25-25.4)                                                                                                                   |
| Cardiovascular disease | 11 689                                                                             | 12.8 (12.5-13)                                             | 9.4 (9.2-9.5)                                                                 | 75 399 12.1 (12.1-12.2)                                     | 7.7 (7.6-7.8)                                                                                                                   |
| Diabetes specific causes | 2536                                                                               | 2.8 (2.7-2.9)                                              | 2.1 (4.1-2.2)                                                                  | 12 432 2 (2-2)                                              | 1.5 (1.5-1.6)                                                                                                                   |
| Renal failure  | 230                                                                               | 0.25 (0.22-0.29)                                            | 0.2 (0.2-0.2)                                                                  | 1417 0.23 (0.22-0.24)                                       | 0.2 (0.1-0.2)                                                                                                                   |
| Cancer         | 6281                                                                              | 6.9 (6.7-7)                                                 | 4.8 (4.7-4.9)                                                                  | 58 621 9 (9.4-9.5)                                          | 5.2 (5.2-5.3)                                                                                                                   |
| Respiratory disease | 5000                                                                               | 5.5 (5.3-5.6)                                              | 4 (3.9-4.2)                                                                    | 33 477 5.4 (5.3-5.4)                                        | 3.6 (3.5-3.6)                                                                                                                   |

aDiabetes mellitus (International Classification of Disease-10 codes E10-E14), drug-induced hypoglycaemia without coma (E16.0) and unspecified hypoglycaemia (E16.2).
processes, whilst 37,235 (20.8%) had received five or fewer care processes in the same period. The corresponding figures for people with type 2 diabetes were 878,605 (62.9%), 387,060 (27.6%) and 132,125 (9.5%), respectively.

### 3.1 Characteristics by number of care processes received

Care process completion variation showed little relation to deprivation but was associated with age, ethnicity, HbA1c and smoking status (Table 1). The mean age of those with type 1 diabetes recorded as having received five or fewer care processes was 40.6 years compared to mean ages of 46.3 and 51.0 years for those recorded as receiving six or seven care processes and all eight recommended care processes, respectively \( (P < 0.005) \). For those with type 2 diabetes, the mean ages were 60.9, 63.5 and 65.0 years, respectively \( (P < 0.005) \). A total of 97.6% of those with type 1 and 97.6% of those with type 2 diabetes had a valid ethnic group recorded. Among those with type 1 diabetes, 89.1% of those recorded as receiving five or fewer care processes and 87.9% recorded as receiving all eight care processes were from White ethnic groups \( (P < 0.005) \); the corresponding proportions in those with type 2 diabetes were 73.3% and 80.8% \( (P < 0.005) \). The latest mean HbA1c recorded between January 1, 2009 and March 31, 2010 was higher in those recorded as receiving fewer care processes: in people with type 1 diabetes, it was 72 mmol/mol (8.7%) for five or fewer, 70.3 mmol/mol (8.6%) for six or seven compared to 68 mmol/mol (8.4%) for eight care processes \( (P < 0.005) \), and in those with type 2 diabetes, it was 62 mmol/mol (7.8%) for five or fewer, 58.4 mmol/mol (7.5%) for six or seven and 57 mmol/mol (7.4%) for eight care processes \( (P < 0.005) \). Smoking prevalence recorded between January 1, 2009 and March 31, 2010 was higher among those receiving fewer care processes: 32.9% for five or fewer versus 19.9% for eight care processes in type 1 diabetes \( (P < 0.005) \) and 26.8% versus 13.7% in type 2 diabetes \( (P < 0.005) \).

A breakdown of the individual care processes received is provided in Tables S1 and S2.

### 3.2 Mortality by number of care processes received

Over the period January 1, 2012 to December 31, 2019 there were 26,915 deaths over 1,431,940 person-years of follow-up in people with type 1 diabetes and 388,093 deaths over 9,853,914 person-years of follow-up in those with type 2 diabetes. The all-cause age- and sex-standardized mortality rate for people with type 1 diabetes with five or fewer care processes was 33.5 per 1000 person years \( (95\% \text{ CI } 32.3-34.8) \), compared to 34.4 \( (95\% \text{ CI } 33.5-35.9) \) for those with six or seven care processes recorded and 30.7 \( (95\% \text{ CI } 29.6-31.8) \) for those with eight care processes recorded. The corresponding figures for people with type 2 diabetes were 30.8 \( (95\% \text{ CI } 30.4-31.1) \), 27.5 \( (95\% \text{ CI } 27.2-27.7) \) and 25.2 \( (95\% \text{ CI } 25.0-25.4) \); Table 2).

After adjustment for age, sex, ethnicity and deprivation, five or fewer processes recorded and having six or seven care processes recorded during the period January 1, 2009 to March 31, 2010 was inversely associated with higher all-cause mortality \( (hazard ratio [HR] < 0.005) \). The latest mean HbA1c recorded between January 1, 2009 and March 31, 2010 was higher in those recorded as receiving fewer care processes: in people with type 1 diabetes, it was 72 mmol/mol (8.7%) for five or fewer, 70.3 mmol/mol (8.6%) for six or seven compared to 68 mmol/mol (8.4%) for eight care processes \( (P < 0.005) \), and in those with type 2 diabetes, it was 62 mmol/mol (7.8%) for five or fewer, 58.4 mmol/mol (7.5%) for six or seven and 57 mmol/mol (7.4%) for eight care processes \( (P < 0.005) \). Smoking prevalence recorded between January 1, 2009 and March 31, 2010 was higher among those receiving fewer care processes: 32.9% for five or fewer versus 19.9% for eight care processes in type 1 diabetes \( (P < 0.005) \) and 26.8% versus 13.7% in type 2 diabetes \( (P < 0.005) \).

### 3.3 Individual care processes

Associations adjusted for age, sex, ethnicity and deprivation were investigated according to individual care process (Table S4). Not having BMI measured was associated with the greatest HR for all-cause mortality \( (1.36 [95\% \text{ CI } 1.30-1.43]) \) for type 1 diabetes and 1.40 \( [95\% \text{ CI } 1.38-1.42] \) for type 2 diabetes), followed by not having a
cholesterol measurement (1.21 [95% CI 1.14-1.28] for type 1 diabetes and 1.22 [95% CI 1.20-1.25] for type 2 diabetes). By contrast, for both type 1 diabetes and type 2 diabetes no record of blood pressure (0.64 [95% CI 0.60-0.69]; 0.67 [95% CI 0.65-0.68]), smoking status (0.86 [95% CI 0.83-0.89]; 0.91 [95% CI 0.90-0.92]) or serum creatinine (0.66 [95% CI 0.62-0.71]; 0.82 [95% CI 0.80-0.84]) were associated with lower mortality hazards. Not having an HbA1c measurement recorded was associated with higher all-cause mortality in type 1 diabetes (HR 1.24 [95% CI 1.16-1.33]) but with lower mortality in type 2 diabetes (HR 0.91 [95% CI 0.89-0.93]).

4 | DISCUSSION

This large national population-based cohort of people with type 1 diabetes and type 2 diabetes followed up for means of 7.6 and 6.9 years, respectively, following 15 months of routine care, finds that having five or fewer recorded care processes during that baseline period was associated with subsequent 7-year hazards of all-cause mortality approximately one-third higher compared to having eight care processes after accounting for demographic characteristics. This higher mortality persists after adjustment for clinical factors known to affect the risk of diabetes-related complications (HbA1c, systolic blood pressure, serum cholesterol, BMI, smoking habit), and cardiovascular and renal comorbidities were taken into account.

The associations were similar between people with type 1 diabetes and type 2 diabetes, at all ages and across socioeconomic groups. In England and Wales most people with type 1 diabetes have specialist-led care while, for type 2 diabetes, most people are managed in a primary care setting. Accordingly, the association between the number of recorded care processes and mortality was independent of the type of care setting. During periods of acute illness or palliative care the medium- to long-term management of diabetes-associated risk may not have clinical priority.
Figure 1  A, Forest plot of the hazard ratio (HR) for all-cause mortality associated with number of care processes recorded between January 1, 2009 and March 31, 2010, stratified by sex, age and ethnicity for people with type 1 diabetes. B, Forest plot of HR for all-cause mortality associated with number of care processes recorded between January 1, 2009 and March 31, 2010 stratified by sex, age and ethnicity for people with type 2 diabetes.
Nonetheless, the association of higher mortality persists in people who had one or more acute hospital admission in the year prior to the assessment of care processes, although the HRs for this group are lower than for those without an acute hospital admission, perhaps reflecting a partial de-prioritization of routine diabetes care at times of acute illness. This finding, combined with the exclusion from the analysis of people who died in the 3-year period after the care processes were assessed, suggest that the association with higher mortality in those not receiving all eight care processes is not solely due to care processes being suspended for clinical reasons. Furthermore, a sensitivity analysis including all people included in the 2009/2010 NDA and still alive on January 1, 2011 did not significantly alter the fully adjusted results of this analysis (Table S6).

For those with type 2 diabetes, but not type 1 diabetes, there were differences by ethnicity in the association between fewer care processes recorded and higher mortality. Among people with type 2 diabetes, the HR of death from all causes amongst those receiving five or fewer annual care processes was 1.29 (95% CI 1.26-1.32) for White ethnicity, 1.13 (95% CI 1.03-1.23) for South Asian ethnicity and 1.34 (95% CI 1.19-1.52) for Black ethnicity. The lower HR in people of South Asian ethnicity may link to their higher risks of developing type 2 diabetes, but lower subsequent mortality. A study using the clinical practice research datalink cohort reported that the additional risk of dying attributable to diagnosed diabetes was lower in people from South Asian ethnic groups than in those from White ethnic groups,15 despite a greater diagnosed incidence of cardiovascular disease.16,17 Thus, the smaller additional diabetes-related mortality risk experienced by people from South Asian ethnic groups compared to White ethnic groups may narrow the additional mortality associated with not receiving care processes. Equally, other factors such as health-related behaviours, health beliefs and cultural differences may influence attitudes to healthcare, in particular routine and preventative care, and thereby play a role in explaining this difference.

No previous study has investigated whether the number of recorded care processes is associated with future outcomes in people with diabetes. Nonattendance at clinics and noncompletion of care processes clearly overlap. A recent comprehensive review of the literature on nonattendance at diabetes outpatient appointments18 found relationships to both logistical and psychosocial factors. It also found associations with nonattendance at diabetes clinics that were similar to those recognized in other medical specialties, such as young age, social deprivation and smoking. Very few studies of nonattendance at diabetes clinics have investigated subsequent outcomes.19 Those that did mostly found associations between infrequent attendance and higher levels of glucose, BMI, blood pressure and lipids, a few studies documented higher emergency hospital use and diabetes-related complications, and just one study, using a composite measure of nonattendance and treatment noncompliance, found higher mortality in people with type 1 diabetes.18,19

As compared to the collective results, analysis of the associations between mortality and noncompletion of individual care processes showed variation from higher risk (eg, BMI, cholesterol and foot examinations) to lower risk (eg, blood pressure, smoking enquiry, serum creatinine). Only one individual care process association with mortality differed between type 1 diabetes and type 2 diabetes. Noncompletion of HbA1c measurement was associated with higher risk in type 1 diabetes but not in type 2 diabetes, perhaps reflecting the greater severity and dominance of hyperglycaemia as a risk factor for complications in type 1 diabetes.

It should be noted that the adjustment of these associations was restricted to age, sex, deprivation and ethnicity as missing data on the risk factors uncovered by the individual care processes hinder more comprehensive adjustments. This means it is plausible that residual confounding and differing risk factor profiles explain these associations. In addition, when carrying out the care processes, previous measurements may influence clinical prioritization, with greater effort being expended on reaching those at previously identified higher risk. It is possible that the proportion of care processes completed is strongly influenced by logistic issues that result in missed appointments, whereas omission of individual items such as weight and surveillance for early complications, may be influenced also by psychosocial factors. Additionally, it may be that some factors recorded as satisfactory and stable at recent visits (eg, HbA1c in people with type 2 diabetes, or blood pressure and kidney function in younger people), are not always repeated, and that a smoking status enquiry may be omitted in long-term nonsmokers, although the primary care pay-for-performance system (Quality and Outcomes Framework) is designed to mitigate against this. Qualitative studies have shown the therapeutic relationship between patient and healthcare professional to be an important determinant of attendance18 but the NDA cannot capture this aspect of care.

The present analysis identifies an association between low numbers of annual care processes completed and subsequent 7-year mortality. Therefore, it identifies a group of people who have a higher risk of mortality. But observational analyses cannot establish cause and effect and we cannot exclude residual confounding. One can only speculate on what any mechanism might be. The prominence of respiratory disease among those who died after low rates of care process completion raises one possibility. Respiratory deaths in younger people are predominantly due to pneumonia, for which diabetes is a known risk factor.20 In our analysis, we tried to account for known pneumonia risks such as smoking, which was more common in the low care process group, and elevated BMI, but we were not able to include other known factors such as high alcohol intake, poor diet and low physical activity. Conceivably, these unmeasured risks triangulate with the likelihood of missing care processes. Alternatively, individuals more engaged with self-care and lower risk lifestyles may attend clinics more often and be keener to complete all the care processes. Equally, the findings may be due to reverse causality, whereby people with multimorbidities, particularly mental illness, will be less likely to engage with routine follow-up and self-management.

Strengths of the present study include the size of the cohort included in the analysis, covering 76% of practices in England and Wales, the fact that it is drawn from a comprehensive selection of real-world population-based healthcare records, and the length of the
follow-up. An important limitation is that neither medication data nor influenza and pneumonia immunizations were available for this analysis, and these could have shed some light on healthcare interactions. The nature of this analysis means that if people have not received a specific care process the risk factor data arising from that process are missing. In this analysis all variables included in the Cox proportional hazard regression models are treated as categorical variables and have a category for “missing” data. Whilst this does not completely eradicate residual confounding due to missing data, it is much reduced. It is not possible to distinguish the separate or joint contributions of inertia from patients or healthcare professionals to undertaking of care processes and therefore the recording of risk factors. To better understand the nature of the associations between the receipt of care processes and disease outcomes and the roles of associations between health beliefs, health behaviours and interactions with healthcare providers requires further qualitative and quantitative work in people with diabetes and their care providers. In addition, the identification of care processes received is limited to a single 15-month period. Variation in interactions with healthcare, and organizational changes to the health service over the follow-up period may have influenced mortality. Data on prescriptions for glucose-lowering drugs were not available for the time period of this analysis. This means that it is not possible to identify whether the associations found in people with type 2 diabetes vary by treatment regimen.

In summary, even when many possible contributory risks for death are taken into account, people with diabetes have a higher mortality risk if their records of routine care indicate several missing annual care processes. Although further evidence is needed on whether efforts to specifically engage this group would yield worthwhile health benefits, health economies should consider how to minimize barriers to receiving the recommended care processes. These observations may be particularly pertinent in contemporary healthcare provision as professionals consider how to organize routine diabetes reviews in the face of the backlog attributable to the direct and indirect effects of COVID-19. It would be all too easy to overlook this high-risk group.

ACKNOWLEDGMENTS

The authors thank Liz Coyle, University of Glasgow, for her assistance in the preparation of this article. N.H. is currently funded by Diabetes UK and NHS England and NHS Improvement. N.H. received funding from the South Asian Health Foundation for this work. N.S. is supported by the British Heart Foundation Research Excellence Award (RE/18/6/34217).

CONFLICT OF INTERESTS

Naomi Holman, Bob Young, Naveed Sattar, Kamlesh Khunti, Sarah H. Wild, Edward W. Gregg and Jonathan Valabhji are members of the National Diabetes Audit Research Advisory Group. Naveed Sattar has received grant and personal fees from Boehringer Ingelheim, and personal fees from Amgen, AstraZeneca, Eli Lilly, Merck Sharp & Dohme, Novartis, Novo Nordisk, Pfizer, and Sanofi outside the submitted work. Kamlesh Khunti has acted as a consultant, speaker or received grants for investigator-initiated studies for AstraZeneca, Novartis, Novo Nordisk, Sanofi-Aventis, Lilly and Merck Sharp & Dohme, Boehringer Ingelheim, Bayer, Berlin-Chemie AG/Menarini Group, Janssen, and Napp. Jonathan Valabhji is the National Clinical Director for Diabetes and Obesity at NHS England and NHS Improvement. All other authors declare no relationships or activities that could appear to have influenced the submitted work.

AUTHOR CONTRIBUTIONS

The study was designed by Roger Gadsby, Bob Young, Naomi Holman and Naveed Sattar. Naomi Holman undertook the statistical analysis. All authors reviewed the methods, assisted in writing the paper, reviewed the final manuscript, and gave approval for publication. Naomi Holman is the guarantor and accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1111/dom.14528.

DATA AVAILABILITY STATEMENT

Information governance rules for the National Diabetes Audit prevent the raw or processed data used in this analysis being made publicly available.

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