BMJ Open

Characterising the burden of chronic kidney disease among people with type 2 diabetes in England: a cohort study using the Clinical Practice Research Datalink

Sarah Cook,[1,2] Niklas Schmedt,[3] Julie Broughton,[4] Philip A Kalra,[5,6] Laurie A Tomlinson ,[2] Jennifer K Quint [1]

To cite: Cook S, Schmedt N, Broughton J, *et al*. Characterising the burden of chronic kidney disease among people with type 2 diabetes in England: a cohort study using the Clinical Practice Research Datalink. *BMJ Open* 2023;**13**:e065927. doi:10.1136/bmjopen-2022-065927

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2022-065927).

Received 22 June 2022
Accepted 07 February 2023

For numbered affiliations see end of article.

Correspondence to
Dr Sarah Cook;
sarah.cook@imperial.ac.uk

ABSTRACT

Objectives To describe prevalence of chronic kidney disease (CKD), demographic and clinical characteristics, treatment patterns and rates of cardiovascular and renal complications for patients with type 2 diabetes (T2D) treated in routine clinical care.

Design Repeat cross-sectional study (6 monthly cross-sections) and cohort study from 1 January 2017 to 31 December 2019.

Setting Primary care data from English practices contributing to the UK Clinical Practice Research Datalink linked to Hospital Episode Statistics and Office for National Statistics mortality data.

Participants Patients with T2D aged >18 years, at least one year of registration data.

Primary and secondary outcomes Primary outcome was prevalence of CKD defined as chronic kidney disease epidemiology collaboration (CKD-EPI) estimated glomerular filtration rate <60 mL/min/1.73 m^2, and/or urinary albumin creatinine ratio ≥3 mg/mmol in the past 24 months. Secondary outcomes were prescriptions of medications of interest and clinical and demographic characteristics in the past 3 months. In the cohort study rates of renal and cardiovascular complications, all-cause mortality and hospitalisations over the study period were compared among those with and without CKD.

Results There were 574 190 eligible patients with T2D as of 1 January 2017 and 664 296 as of 31 December 2019. Estimated prevalence of CKD across the study period was stable at approximately 30%. Medication use was stable over time in people with CKD and T2D, with low use of steroidal mineralocorticoid receptor antagonists (approximately 4.5% across all time points) and a low use but steady increase in use of sodium-glucose co-transporter-2 inhibitors (from 2.6% to 6.2%). Rates of all complications were higher in those with CKD at the start of the study period, with increasing rates, with increased severity of CKD, heart failure and albuminuria.

Conclusions The burden of CKD in patients with T2D is high and associated with substantially increased rates of complications particularly in those with comorbid heart failure.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ There was a large sample size of over half a million patients.
⇒ The use of linked electronic health records allowed us to investigate a wide range of clinical risk factors and real-world prescribing of medications.
⇒ Definition of chronic kidney disease was limited to what data could be obtained from recording of laboratory results in routine practice which may have resulted in measurement error.

INTRODUCTION

Globally the prevalence of type 2 diabetes (T2D) is increasing, and chronic kidney disease (CKD) is a frequent complication of diabetes, affecting up to 40% of patients with T2D.[1–3] CKD is defined as a progressive, irreversible loss of kidney function that usually happens gradually over years, potentially resulting in end-stage renal disease (ESRD).[4] There is a continuum of development, progression and complications of CKD. Comorbidities are common and patients with CKD may have a variety of conditions, such as diabetes, hypertension and cardiovascular diseases (CVD) including heart failure.[5–9]

Among people with T2D, comorbid CKD confers a substantial morbidity and mortality burden. Not only is CKD in T2D the leading cause of ESRD, it also increases the risk of CVD: Patients with CKD and T2D are three times more likely to die from a CVD-related cause than those with T2D alone. CVD death is as common in patients with CKD, as it is in people with T2D.[10 11] Excess mortality among people with T2D is accentuated in the subgroup with comorbid CKD.[12]

Currently, contemporary data on the prevalence of CKD in patients with T2D in England is scarce. In the UK, a Department of Health report from 2006 estimated that around 30% of patients with T2D develop CKD.[13] Additionally, there is limited contemporary data regarding patient characteristics, treatment patterns and rates of cardiovascular

and renal complications in patients with CKD and T2D within England. While CKD is a well-known complication of T2D[1–3] it is important to quantify this burden in order to guide adequate healthcare provision to meet patient needs. It is also important to identify and quantify the disease burden in patient groups where the disease burden is expected to be higher (eg, in patients with particular comorbidities) and to investigate what extent patients are receiving appropriate medication in order to improve patient management. This is timely as new treatment options have recently become available for reducing risk in these patients.

The aim of this study was to characterise the burden of disease due to CKD in patients with T2D in the English primary care population and to describe this patient population in more detail than has been done previously. The research objectives were (1) to describe prevalence of CKD overall and by a broad range of demographic and clinical characteristics, (2) to investigate medication use among people with both CKD and T2D and (3) describe rates of cardiovascular and renal complications for patients with T2D treated in routine clinical care over a 3-year period

METHODS

Study sample

The study was undertaken using data obtained from the Clinical Practice Research Datalink (CPRD) Aurum database,[14] with linked data for hospitalisations coming from Hospital Episode Statistics (HES) and on deaths obtained from the Office of National Statistics (ONS). The CPRD database consists of routinely collected, anonymised electronic healthcare record data from general practices in the UK covering 13% of the English population in 2018; HES contains data on patients admitted to National Health Service hospitals in England; and the ONS data contains information on date and cause of death. In total, 75% of English practices in CPRD have provided information allowing for linkage of patients to other data sources, including HES and ONS data. Linked pseudonymised data was provided for this study by CPRD. Data is linked by NHS Digital, the statutory trusted third party for linking data, using identifiable data held only by NHS Digital. Select general practices consent to this process at a practice level with individual patients having the right to opt-out.

The study population was adults aged over 18 years of age with T2D, defined using a codelist available within the Project Github repository NHLI-Respiratory-Epi/ABC-CKD (github.com). Patients were included in analyses at each time point if they had a code indicating T2D and had been registered for at least 1 year with their general practitioner (GP) prior to that date and had linked HES and ONS data available.

Study design

Two study designs were used to address the study objectives (1) a repeat cross-sectional study and (2) a cohort study:

1. Prevalence of CKD and medication use over time was assessed using a series of retrospective cross-sectional analyses comprising all patients identified as having T2D in the UK CPRD Aurum population linked with other national electronic healthcare databases (HES and ONS) at 6-month intervals from 1 January 2017 until 31 December 2019. CKD severity in terms of Kidney Disease Improving Global Outcome (KDIGO) classification and clinical and demographic characteristics of patients were assessed at the end of the study period (31 December 2019).
2. Rates of adverse outcomes by CKD status at baseline (1 January 2017) was assessed using a cohort study comprising all patients in the UK CPRD Aurum population linked with other national electronic healthcare databases (HES and ONS). All patients with T2D and CKD meeting minimum age and data quality requirements were used to determine the occurrence of all-cause mortality, hospitalisation, CVD and renal events.

Variable definitions

CKD

Patients were categorised as having a degree of CKD if they had at least one estimated glomerular filtration rate (eGFR) or recorded urinary albumin creatinine ratio (UACR) measurement in the previous 24 months indicating the following: eGFR <60 mL/min/1.73 m^2 and/or UACR ≥3 mg/mmol. We calculated eGFR using the most recent creatinine measure within 24 months, using the chronic kidney disease epidemiology collaboration (CKD-EPI) equation without regard to ethnicity. Only one measurement was considered in the primary definition of the outcome, since guidelines recommend eGFR testing in patients with T2D once a year, that is, a second measurement would not reflect clinical practice and potentially lead to an underestimation of CKD. For convenience we refer to the outcome as CKD throughout, in keeping with other epidemiological studies.[15]

CKD severity was classified using KDIGO stages: G1 (90+ mL/min/1.73 m^2), G2 (60–89 mL/min/1.73 m^2), G3a (45–59 mL/min/1.73 m^2), G3b (30–44 mL/min/1.73 m^2), G4 (15–29 mL/min/1.73 m^2), G5 (<15 mL/min/1.73 m^2), based on eGFR measures (mL/min/1.73 m^2) and urine albumin excretion, UACR A1 (<3 mg/mmol), A2 (3–30 mg/mmol) and A3 (>30 mg/mmol).

Demographic and clinical characteristics

A broad range of demographic and clinical characteristics were included with the aim of providing a comprehensive description of the patient population. Demographic characteristics of the sample investigated were age, gender and ethnicity. Clinical characteristics were body mass index, serum potassium, systolic blood pressure, anaemia, other diabetic complications (retinopathy and neuropathy) and cardiovascular risk factors and comorbidities (hypertension, lipid disorders, coronary artery disease (CAD), stroke, myocardial

infarction, peripheral artery disease, atrial fibrillation/flutter and heart failure).

Codelists and stata code used to define these variables are available within the Project Github repository NHLI-Respiratory-Epi/ABC-CKD (github.com).

Medication use

The key medications of interest were commonly prescribed cardiovascular medications and selected recommended antidiabetic medications: angiotensin converting enzyme-inhibitors (ACE-I), angiotensin receptor blockers (ARBs), steroidal mineralocorticoid receptor antagonists (sMRA)s, beta-blockers, calcium channel blockers, oral diuretics, lipid lowering drugs, sodium-glucose co-transporter-2 inhibitors (SGLT2i), dipeptidyl peptidase 4 inhibitors (DDP4) and GLP-1 receptor agonists (GLP-1). Medication use was defined as having prescriptions in the 3 months prior to the respective time point.

Renal and cardiovascular complications

Occurrence of (1) a renal composite outcome, that is, first occurrence of kidney failure—defined as eGFR <15 mL/min/1.73 m^2 or initiation of chronic dialysis (haemodialysis or peritoneal dialysis) or renal transplantation—as well as occurrence of (2) individual outcomes and composite of cardiovascular complications, that is, cardiovascular death, first occurrence of non-fatal myocardial infarction, non-fatal stroke or hospitalisation for heart failure. All single components were also assessed as separate endpoints. Further outcomes included (3) all-cause mortality and (4) all-cause hospitalisation (first occurrence during time period). Outcomes were defined in primary and secondary care data as appropriate. Codes used to define outcomes are available within the Project Github repository NHLI-Respiratory-Epi/ABC-CKD (github.com).

Statistical analysis

Prevalence of CKD in T2D and demographic and clinical characteristics

Prevalence was calculated at each time point by demographic and clinical characteristics. The numerator consisted of patients with both CKD and T2D irrespective of whether it was incident or not. The denominator consisted of all patients meeting the eligibility criteria at a certain time point or over the study period with T2D with at least one valid eGFR or UACR measurement in the last 24 months. Prevalent cases consisted of both patients with prior evidence of the conditions and those developing the conditions over the time periods of interest. Patients could have the conditions prior to cohort entry (ie, recorded as present at baseline) or develop the conditions after cohort entry.

A sensitivity analysis was conducted related to the choice of the denominator to calculate the prevalence of CKD in T2D considering all patients with T2D in the denominator, irrespective of whether an eGFR or UACR measurement was available in the past 24 months ('denominator 2').This sought to demonstrate whether prevalence estimates were substantially affected by the presence of missing data.

Demographic and clinical features of those with both T2D and CKD at the start and end of the study period was described using percentages for categorical variables and means and SD, or medians and IQR for continuous variables.

Prevalence of medication use in patients with CKD and T2D

The proportion of patients receiving medications of interest was assessed at each time point in the T2D population overall and in those with comorbid T2D and CKD. Prevalence of medication use among those with CVD, coronary artery disease, heart failure and albuminuria was additionally investigated among those with T2D and CKD at the end of the study period.

Occurrence of renal and cardiovascular complications in patients with CKD and T2D

Occurrence of renal and cardiovascular complications was assessed over the follow-up period in the entire population and by CKD severity, use of ARBs and/or ACE-I, comorbid hypertension, heart failure and CVD.

The incidence rate of individual disease complications, and of a composite endpoint, per 1000 person-years was also estimated. The numerator consisted of the outcomes and the denominator included person-time (in years) from 1 January 2017 until the date of the outcome (ie, first event for each outcome of interest), death (when it was not the outcome), date of disenrolment in the primary care practice or of inclusion in CPRD, or the end of the study period (or time period of interest).

Patient and public involvement

Patients and the public were not involved in the development of this manuscript.

RESULTS

The total number of eligible participants included at the start (1 January 2017) was 574 190 and at the end of follow-up (31 December 2019) was 664 296. The numbers of participants excluded at each of the study periods are shown in online supplemental figure 1.

The demographic and clinical characteristics of the total study population with T2D and prevalence of CKD at the end of the study period (31 December 2019) are shown in table 1. The equivalent data for eligible participants at the start of the study (1 January 2017) are shown in online supplemental table 1. The majority (95.2%) of participants had a recording of at least one of serum creatinine or UACR in the past 24 months.

Prevalence of CKD in T2D and demographic and clinical characteristics

The primary outcome of interest was CKD. The overall prevalence of CKD among those with a valid measurement of CKD status on 31 December 2019 was 29.1% (table 1). The prevalence estimate only changed slightly

Table 1 Prevalence of CKD in the past 24 months in specific patient populations and characteristics of study population with type 2 diabetes at end of study period on 31 December 2019

	Prevalence of CKD (reduced eGFR and/or albuminuria) by denominator 1*		Prevalence of CKD (reduced eGFR and/or albuminuria) by denominator 2†		Denominator 1*		Denominator 2†	
	N	(row %)	N	(row %)	N	(column %)	N	(column %)
Total sample	183 997	(29.1)	183 997	(27.7)	632 729	(100)	664 296	(100)
Gender								
Male	99 458	(28.5)	99 458	(27.2)	348 608	(55.1)	365 383	(55.0)
Female	84 539	(29.8)	84 539	(28.3)	284 121	(44.9)	298 913	(45.0)
Age (years)								
Mean (SD)	–	–	–	–	66.1	(14.5)	65.6	(14.8)
18–29	704	(7.9)	704	(6.3)	8886	(1.4)	11 224	(1.7)
30–39	2280	(11.6)	2280	(10.1)	19 621	(3.1)	22 649	(3.4)
40–49	6980	(13.2)	6980	(12.0)	52 856	(8.4)	58 013	(8.7)
50–59	18 358	(15.6)	18 358	(14.7)	117 477	(18.6)	124 893	(18.8)
60–69	32 612	(21.2)	32 612	(20.4)	154 100	(24.4)	160 199	(24.1)
70–79	54 836	(34.1)	54 836	(33.2)	160 834	(25.4)	165 285	(24.9)
80–89	54 246	(54.8)	54 246	(53.5)	99 006	(15.7)	101 329	(15.3)
>90	13 981	(70.1)	13 981	(67.5)	19 949	(3.2)	20 704	(3.1)
Ethnicity								
White	124 297	(30.0)	124 297	(28.7)	414 234	(65.5)	433 647	(65.3)
South Asian	19 137	(26.4)	19 137	(25.5)	72 402	(11.4)	74 922	(11.3)
Black	9482	(28.2)	9482	(26.7)	33 687	(5.3)	35 458	(5.3)
Other	2546	(25.2)	2546	(23.9)	10 123	(1.6)	10 651	(1.6)
Mixed	1775	(25.9)	1775	(24.4)	6842	(1.1)	7283	(1.1)
Not stated	8871	(27.2)	8871	(25.6)	32 571	(5.2)	34 611	(5.2)
Missing (No code)	17 889	(28.5)	17 889	(26.4)	62 870	(9.9)	67 724	(10.2)
Body mass index (kg/m^2)								
<25	33 475	(29.9)	33 475	(27.9)	111 949	(17.7)	119 790	(18.0)
25–29	62 340	(29.3)	62 340	(28.0)	212 532	(33.6)	222 330	(33.5)
30–39	72 567	(29.0)	72 567	(27.9)	250 187	(39.5)	260 322	(39.2)
≥40	14 472	(26.9)	14 472	(25.7)	53 758	(8.5)	56 285	(8.5)
Missing	1143	(20.5)	1143	(20.5)	4303	(0.7)	5569	(0.8)
eGFR (mL/min/1.73 m^2)								
G1 (>90)	–		–	–	255 145	(40.3)	255 145	(38.4)
G2 (60–89)	–		–	–	256 876	(40.6)	256 876	(38.7)
G3a (45–59)	–		–	–	60 060	(9.5)	60 060	(9.0)
G3b (30–44)	–		–	–	30 883	(4.9)	30 883	(4.7)

Continued

Table 1 Continued

	Prevalence of CKD (reduced eGFR and/or albuminuria) by denominator 1*		Prevalence of CKD (reduced eGFR and/or albuminuria) by denominator 2†		Denominator 1*		Denominator 2†	
	N	(row %)	N	(row %)	N	(column %)	N	(column %)
G4(15–29)	–		–	–	9632	(1.5)	9632	(1.5)
G5 (<15)	–		–	–	2722	(0.4)	2722	(0.4)
No valid measurement	–		–	–	17411	(2.8)	48978	(7.4)
Urine albumin: creatinine ratio (mg/mmol)								
A1 (<3)	–		–	–	280876	(44.4)	280876	(42.3)
A2(3–30)	–		–	–	97928	(15.5)	97928	(14.7)
A3(>30)	–		–	–	18904	(3.0)	18904	(2.9)
No valid measurement	–		–	–	235021	(37.1)	266588	(40.1)
CKD (eGFR<60)	–		–	–	103297	(16.3)	103297	(15.6)
Albuminuria (A2+A3)	–		–	–	116832	(18.5)	116832	(17.6)
Most recent measure systolic blood pressure in past 18 months								
Mean (SD)	–		–	–	131.5	(14.4)	131.4	(14.4)
Missing	–		–	–	28763		44612	
Most recent measure serum potassium in past 18 months—median (IQR)	–		–	–	4.5	(4.2–4.8)	4.5	(4.2–4.8)
Potassium level (hyperkalaemia)								
≤5.5 mmol/L	167516	(29.1)	167516	(29.1)	575793	(91.0)	576567	(86.8)
>5.5 mmol/L	4027	(57.4)	4027	(57.3)	7013	(1.1)	7026	(1.1)
>6.0 mmol\L	910	(63.4)	910	(63.2)	1435	(0.2)	1439	(0.2)
Missing	11544	(23.8)	11544	(14.6)	48488	(7.7)	79264	(11.9)
Hypertension (medcode)	141958	(36.8)	141958	(35.8)	386147	(61.0)	396638	(59.7)
Hypertension (medcode or medication‡)	164027	(35.8)	164027	(34.9)	457842	(72.4)	470182	(70.8)
Hypotension (medcode)	9576	(50.2)	9576	(48.9)	19076	(3.0)	19599	(3.0)
Heart failure	25278	(57.9)	25278	(56.8)	43696	(6.9)	44535	(6.7)
Angina	29501	(45.1)	29501	(44.2)	65358	(10.3)	66687	(10.0)
Myocardial infarction	19317	(44.1)	19317	(43.1)	43793	(6.9)	44794	(6.7)
Coronary artery disease (CAD)	45353	(43.9)	45353	(42.9)	103426	(16.4)	105667	(15.9)
Stroke	24904	(44.8)	24904	(43.6)	55588	(8.8)	57073	(8.6)
Atrial fibrillation/flutter	29462	(53.1)	29462	(52.1)	55502	(8.8)	56544	(8.5)
Peripheral artery disease (PAD)	13405	(49.2)	13405	(48.0)	27243	(4.3)	27901	(4.2)
Cardiovascular disease (CAD, PAD, stroke, myocardial infarction or angina)	67463	(43.0)	67463	(42.0)	156881	(24.8)	160720	(24.2)
Lipid disorder (medcode or lipid lowering drug)	142311	(32.4)	142311	(31.6)	439804	(69.5)	450283	(67.8)
Diabetic retinopathy	89538	(37.1)	89538	(35.9)	241528	(38.2)	249492	(37.6)
Diabetic neuropathy	12607	(46.7)	12607	(45.7)	26973	(4.3)	27617	(4.2)
Anaemia (medcode)	50564	(43.5)	50564	(42.3)	116191	(18.4)	119465	(18.0)

Continued

Table 1 Continued

	Prevalence of CKD (reduced eGFR and/or albuminuria) by denominator 1*		Prevalence of CKD (reduced eGFR and/or albuminuria) by denominator 2†		Denominator 1*		Denominator 2†	
	N	(row %)	N	(row %)	N	(column %)	N	(column %)
Prescribed ACE inhibitor in past 3 months	76485	(34.7)	76485	(34.1)	220343	(34.8)	224545	(33.8)
Prescribed ARB in past 3 months	40236	(40.2)	40236	(39.5)	100202	(15.8)	101829	(15.3)
Prescribed ACE inhibitor and/or ARB in past 3 months	115774	(36.4)	115774	(35.7)	318485	(50.3)	324280	(48.8)
Prescribed sMRA in past 3 months	8128	(51.9)	8128	(50.9)	15655	(2.5)	15956	(2.4)
Prescribed SGLT2I in past 3 months	11383	(22.0)	11383	(21.7)	51664	(8.2)	52512	(7.9)
Prescribed DDP4 in past 3 months	37180	(39.6)	37180	(39.0)	93998	(14.9)	95403	(14.4)
Prescribed GLP-1 in past 3 months	7489	(31.9)	7489	(31.4)	23468	(3.7)	23882	(3.6)
Prescribed lipid lowering medication in past 3 months	131863	(32.7)	131863	(32.0)	403782	(63.8)	411731	(62.0)
Prescribed beta-blockers in past 3 months	61301	(42.7)	61301	(41.9)	143609	(22.7)	146431	(22.0)
Prescribed calcium channel blockers in past 3 months	69442	(37.9)	69442	(37.2)	183019	(28.9)	186624	(28.1)
Prescribed oral diuretic in past 3 months	29184	(38.6)	29184	(37.9)	75675	(12.0)	77013	(11.6)
Prescribed insulin in past 3 months	40658	(37.7)	40658	(36.1)	107796	(17.0)	112517	(16.9)
Prescribed biguanides in past 3 months	95500	(28.2)	95500	(27.7)	338336	(53.5)	345046	(51.9)
Prescribed sulfonylureas in past 3 months	2483	(38.1)	2483	(37.5)	6519	(1.0)	6630	(1.0)
Prescribed antiplatelet drugs in past 3 months	56771	(40.2)	56771	(39.4)	141139	(22.3)	143945	(21.7)

*Denominator 1: type 2 diabetes (≥1 code for type 2 diabetes on 31 December 2019) and eligible measure either reduced eGFR and/or albuminuria.
†Denominator 2: type 2 diabetes (≥1 code for type 2 diabetes on 31 December 2019).
‡Hypertension medication prescribed in the past 3 months (ACE-I, ARB, calcium channel blocker, beta-blocker and oral diuretic).
ACE-I, angiotensin converting enzyme-inhibitor; ARB, angiotensin receptor blocker; CKD, chronic kidney disease; DDP4, dipeptidyl peptidase 4 inhibitors; eGFR, estimated glomerular filtration rate; GLP-1, GLP-1 receptor agonists; SGLT2i, sodium-glucose co-transporter-2 inhibitors; sMRA, steroidal mineralocorticoid receptor antagonists.

when using Denominator 2 (27.7%). The equivalent results for the 1 January 2017 were 28.1% using Denominator 1 and 27.1% using Denominator 2 (online supplemental table 1).

The prevalence of CKD among patients with T2D across seven time points between 1 January 2017 and 31 December 2019 is shown in table 2. The prevalence of CKD was relatively stable throughout the study period ranging from 27.9% to 29.1% using Denominator 1. The prevalence was not strongly affected by the choice of denominator with the difference between prevalence by choice of denominator ranging from 1% to 1.4%.

The prevalence of CKD by demographic characteristics and comorbidities at the end of study period 31 December 2019 is shown in table 1. The prevalence of CKD using denominator 1 on 31 December 2019 was 43.0% in patients with CVD, 57.9% in patients with heart failure, 35.8% in patients with hypertension and 36.4% in patients prescribed ACE-I or ARBs. The equivalent findings for 1 January 2017 are shown in online supplemental table 1. Findings were consistent between the two time periods.

The distribution of patients with T2D within the KDIGO grid showing degree of CKD disease severity for the end of the study period 31 December 2019 is shown in table 3. As of 31 December 2019 there were higher levels of missing data for UACR (40.1%) than eGFR (7.4%), with the highest level of missing data for UACR among those with eGFR indicative of CKD stages 1 and 2 (16.6% and 14.1%, respectively) while among those with stage 5 CKD, only 0.2% were missing a UACR measurement.

The demographic and clinical characteristics of patients with CKD and T2D at the end of the study on 31 December 2019 are shown in table 4. The equivalent findings for the start of the study period 1 January 2017 are shown in online supplemental table 2. Characteristics of patients with both CKD and T2D were similar at both time points.

Prevalence of medication use in patients with CKD and T2D

The prevalence of the use of medications (ACE-I, ARBs, beta-blockers, calcium channel blockers, oral diuretics, DDP4i, SGLT2-i, GLP-1a and sMRAs) among those with T2D and CKD over time are shown in online supplemental table 3 and figure 2. For the majority of medications use remained relatively consistent over time, including use of sMRAS. A notable exception was SGLT-2i use which increased from 2.6% on 1 January 2017 to 6.2% on the 31 December 2019. There were also increases in use of DDP-4 (16.5% to 20.2%) and GLP-1 (2.2% to 4.1%) and a decrease in prevalent prescribing of ACE-I (46.0% to 41.6%).

The prevalence of medication use in selected subgroups of interest among patients with both CKD and T2D as of 31 December 2019 is shown in table 5. For the subgroup with hypertension, medication use was not included in the definition to avoid double counting however as expected use of antihypertensives was lower in those with no Read codes for hypertension. For all other subgroups prevalence of use of medications was fairly consistent with the exception of higher use of beta-blockers among those

Table 2 Cross-sectional prevalence of composite CKD outcome among those with type 2 diabetes across seven time points in those with linked data

		1 January 2017		1 July 2017		1 January 2018		1 July 2018		1 January 2019		1 July 2019		31 December 2019	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%
CKD by component/ denominator 1	No CKD	397305	71.9	409251	72.1	416873	71.8	426695	71.7	435771	71.5	441979	70.9	448732	70.9
	Albuminuria only	60123	10.9	62123	10.9	64450	11.1	68239	11.4	70997	11.7	78991	12.7	80700	12.8
	Reduced eGFR only	65522	11.9	67027	11.8	68842	12.3	68393	11.4	69532	11.4	66747	10.7	67165	10.6
	Both	29706	5.4	29494	5.2	30456	5.2	31568	5.3	33112	5.4	35957	5.8	36132	5.7
CKD/denominator 1	Yes	155351	28.1	158644	27.9	163748	28.2	168200	28.3	173641	28.5	181695	29.1	183997	29.1
CKD/denominator 2	Yes	155351	27.1	158644	26.8	163748	27.1	168200	27.1	173641	27.3	181695	27.9	183997	27.7
Denominator 1: valid albumin:creatinine urine measurement OR valid eGFR measurement within 24 months of time X		552656	100	567895	100	580621	100	594895	100	609412	100	623674	100	632729	100
Denominator 2: all with type 2 diabetes at time point X		574190	100	591208	100	605327	100	621607	100	637024	100	651520	100	664296	100

*CKD defined as either eGFR <60 (mL/min/1.73 m^2) OR albumin:creatinine urine ratio ≥3 mg/mmol.
CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate.

Table 3 Stratification by stage of chronic kidney disease and degree of albuminuria for all patients with type 2 diabetes on 31 December 2019 (%)

	UACR				
eGFR	A1 <3/mg/mmol	A2 3–30 mg/mmol	A3 >30 mg/mmol	Missing	Total
Stage 1 ≥90	16.98	4.38	0.49	16.56	38.41
Stage 2 60–89	18.11	5.72	0.76	14.08	38.67
Stage 3a 45–59	3.69	2.12	0.46	2.77	9.04
Stage 3b 30–44	1.45	1.40	0.50	1.31	4.65
Stage 4 15–29	0.23	0.42	0.36	0.44	1.45
Stage 5 <15	0.01	0.05	0.13	0.22	0.41
Missing	1.82	0.66	0.14	4.75	7.37
Total	42.28	14.74	2.85	40.13	100.00

*Denominator: all eligible patients with type 2 diabetes on 31 December 2019.
eGFR, estimated glomerular filtration rate; UACR, urinary albumin creatinine ratio.

with CVD and heart failure, and higher use of SGLTi-2s among those with albuminuria.

The prevalence of hypertension and heart failure stratified by sMRAs use on 31 December 2019 is shown in online supplemental table 4. Almost all sMRAs users had either hypertension or heart failure (98.7%). The prevalence of hypertension was high in both users and non-users. There was a large difference in the prevalence of heart failure with a much higher prevalence in sMRAs users (66.7%) compared with non-users (11.3%).

Occurrence of renal and cardiovascular complications in patients with CKD and T2D

The rate of complications (all-cause mortality, all-cause hospitalisation, CVD hospitalisation and mortality, ESRD) in those with prevalent CKD at the start of the study period (1 January 2017) are shown in table 6. The rate of all outcomes was higher in those with CKD (eg, all-cause mortality 85.8 per 1000 person years, CVD composite outcome 49.1 per 1000 person years, ESRD 10.0 per 1000 person years) than those without CKD (all-cause mortality 26.7 per 1000 person years, CVD composite outcome 15.1 per 1000 person years, ESRD 1.0 per 1000 person years). The rate of all outcomes was higher among those with more severe CKD as indicated by lower eGFR and/or UACR of A3. Among those with T2D, CKD and additional comorbidities (CAD, hypertension, heart failure) the rate of all complications was higher than in those with CKD and T2D without these CVD conditions with particularly high rates among those with heart failure (all-cause mortality 192.9 per 1000 person years, CVD composite outcome 149.0 per 1000 person years, ESRD 19.4 per 1000 person years). Conversely, the rate of adverse outcomes was lower among those with CKD and T2D who had been prescribed an ACE-I or ARB in the previous 3 months.

DISCUSSION

Principal findings

In a cohort of over half a million people with T2D in English primary care, the prevalence of CKD was approximately 30%. This was consistent over a 3-year time period (1 January 2017 to 31 December 2019) and was not substantially different dependent on the denominator that was used (the entire population or restriction to those with a valid measurement of CKD status in the past 24 months).

Medication use in patients with CKD and T2D was largely stable over time with the exception of SGLT2is and DDP4s where use increased over the study period although overall use remained low. Almost all sMRAs users were coded to have either hypertension or heart failure (98.7%).

Medication use was similar among those with comorbidities with the exception of lower use of antihypertensive medication in those without recorded Read codes for hypertension, higher use of beta-blockers among those with CVD and heart failure and higher use of SGLTi-2s among those with recorded albuminuria.

Overall recording of a marker of CKD was very high (95% of patients with type 2 diabetes on 31 December 2019 had a recorded measurement of at least eGFR or UACR). There are however differences in measurement and recording of eGFR and UACR. Measurement of serum creatinine in the previous 24 months among people with T2D was high throughout the study period (>90%) however recording of UACR was substantially lower (approximately 60%). However, we considered this may be due to differential testing based on whether urine dipstick tests were positive or negative based on previous findings from the National Kidney Audit.[16] There was a higher proportion of missing UACR measurements among those with stage 1 or stage 2 disease based on eGFR readings compared with those with stage 3 CKD or worse. Nonetheless, the low recording of albuminuria in this high risk group, with potential for missing a lot of patients with T2D with CKD stages 1 or 2, in an era of increased availability of outcome-modifying treatments is of concern.

People with T2D and CKD were at higher risk of all-cause death, all-cause hospitalisation and adverse CVD

Table 4 Demographic and clinical characteristics of patients with CKD and type 2 diabetes as of 31 December 2019

	Patients with type 2 diabetes and CKD on 31 December 2019	
	N	(column %)
Total sample	183 997	(100)
Gender		
Male	99 458	(54.1)
Female	84 539	(46.0)
Age (years)		
Mean (SD)	73.3	(13.1)
18–29	704	(0.4)
30–39	2280	(1.2)
40–49	6980	(3.8)
50–59	18 358	(10.0)
60–69	32 612	(17.7)
70–79	54 836	(29.8)
80–89	54 246	(29.5)
>90	13 981	(7.6)
Ethnicity		
White	124 297	(67.6)
South Asian	19 137	(10.4)
Black	9482	(5.2)
Other	2546	(1.4)
Mixed	1775	(1.0)
Not stated	8871	(4.8)
Missing (no code)	17 889	(9.7)
Body mass index (kg/m^2)		
<25	33 475	(18.2)
25–29	62 340	(33.9)
30–39	72 567	(39.4)
≥40	14 472	(7.9)
Missing	1143	(0.6)
Most recent systolic blood pressure measurement		
Mean (SD)	133.1	(15.5)
Missing	5107	
Serum potassium		
Median (IQR)	4.6	(4.3–4.9)
Potassium level (hyperkalaemia)		
≤5.5 mmol/L	167 516	(91.0)
>5.5 mmol/L	4027	(2.2)
>6.0 mmol/L	910	(0.5)
Missing	11 544	(6.3)
Hypertension (medcode)	141 958	(77.2)
Hypertension (medcode or medication*)	164 027	(89.2)
Hypotension (medcode)	9576	(5.2)
Heart failure	25 278	(13.7)
Angina	29 501	(16.0)
Myocardial infarction	19 317	(10.5)
Coronary artery disease (CAD)	45 353	(24.7)
Stroke	24 904	(13.5)
Peripheral artery disease (PAD)	13 405	(7.3)
Cardiovascular disease (CAD, PAD, stroke, myocardial infarction or angina)	67 463	(43.0)
Atrial fibrillation/flutter	29 462	(16.0)
Sleep apnoea	8991	(4.9)
Lipid disorder (medcode or lipid lowering drug)	142 311	(77.3)
Diabetic retinopathy	89 538	(48.7)
Diabetic neuropathy	12 607	(6.9)
Anaemia (medcode)	50 564	(27.5)
Prescribed ACE inhibitor in past 3 months	76 485	(41.6)
Prescribed ARB in past 3 months	40 236	(21.9)
Prescibed ACE inhibitor or ARB in past 3 months	115 774	(62.9)
Prescribed sMRA in past 3 months	8128	(4.4)
Prescribed SGLT2I in past 3 months	11 383	(6.2)
Prescribed DDP4 in past 3 months	37 180	(20.2)
Prescribed GLP-1 in past 3 months	7489	(4.1)
Prescribed lipid lowering medication in past 3 months	131 863	(71.7)
Prescribed beta-blockers in past 3 months	61 301	(33.3)
Prescribed calcium channel blockers in past 3 months	69 442	(37.7)
Prescribed oral diuretic in past 3 months	29 184	(15.9)
Prescribed insulin in past 3 months	40 658	(22.1)
Prescribed biguanides in past 3 months	95 500	(51.9)
Prescribed sulfonylureas in past 3 months	2883	(1.4)
Prescribed antiplatelet drugs in past 3 months	56 771	(30.9)

*Hypertension medication prescribed in the past 3 months (ACE-I, ARB, calcium channel blocker, beta-blocker, oral diuretic).
ACE-I, angiotensin converting enzyme-inhibitor; ARB, angiotensin receptor blocker; CKD, chronic kidney disease; DDP4, dipeptidyl peptidase 4 inhibitors; GLP-1, GLP-1 receptor agonists; SGLT2i, sodium-glucose co-transporter-2 inhibitors; sMRA, steroidal mineralocorticoid receptor antagonists.

and renal outcomes over a 3-year follow-up period than those with T2D only, and this risk increased proportionately with worse CKD staging and albuminuria. Patients with CKD and T2D with heart failure and albuminuria were at the highest rates for most outcomes.

Comparison of findings with other studies

While there is limited contemporary data on the prevalence of CKD in people with type 2 diabetes within the UK, the findings of a prevalence of approximately 30% are consistent with a Department of Health report from 2006.[13] Findings with regard testing for kidney function are also consistent with findings from the UK National Kidney Audit in 2017 which also found high levels (86%) of annual testing of eGFR in people with diabetes while testing for UACR was substantially lower (54%). It is worth noting that the criteria used in this paper compared with those from the National Kidney Audit were less stringent as based on testing in the

Table 5 Medication use on 31 December 2019 by subgroups among those with CKD and type 2 diabetes

		ACE-inhibitor		ARBs		Beta-blocker		Calcium channel blocker		Oral diuretics		DDP4		SGLTi-2		GLP-1		sMRAS		Total N (denominator)
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
All with type 2 diabetes and CKD		76485	41.6	40236	21.9	61301	33.3	69442	37.7	29184	15.9	37180	20.2	11383	6.2	7489	4.1	8128	4.4	183997
+ Hypertension (medcode only)	No	12774	30.4	4052	9.6	9448	22.5	4270	10.2	1712	4.1	7867	18.7	3565	8.5	1629	3.9	1513	3.6	42039
	Yes	63711	44.9	36184	25.5	51853	36.5	65172	45.9	27472	19.4	29313	20.7	7818	5.5	5860	4.1	6615	4.7	141958
+Coronary artery disease	No	56819	41.0	29298	21.1	31648	22.8	53069	38.3	22593	16.3	27591	19.9	9401	6.8	5812	4.2	3986	2.9	138644
	Yes	19666	43.4	10938	24.1	29653	65.4	16373	36.1	6591	14.5	9589	21.1	1982	4.4	1677	3.7	4142	9.1	45353
+ Cardiovascular disease (CAD, PAD, stroke, myocardial infarction or angina)	No	47928	41.1	24537	21.1	25114	21.6	43598	37.4	18868	16.2	23136	19.9	8533	7.3	5109	4.4	3101	2.7	116534
	Yes	28557	42.3	15699	23.3	36187	53.6	25844	38.3	10316	15.3	14044	20.8	2850	4.2	2380	3.5	5027	7.5	67463
+Heart failure	No	66044	41.6	33949	21.4	43957	27.7	62618	39.5	24412	15.4	31639	19.9	10674	6.7	6630	4.2	2703	1.7	158719
	Yes	10441	41.3	6287	24.9	17344	68.6	6824	27.0	4772	18.9	5541	21.9	709	2.8	859	3.4	5425	21.5	25278
+UACR 2 or 3	No	14517	40.7	8977	25.2	13940	39.1	11728	32.9	7311	20.5	7324	20.5	636	1.8	1052	3.0	2251	6.3	35687
	Yes	51447	44.0	24537	21.0	35292	30.2	46874	40.1	16388	14.0	24115	20.6	10284	8.8	5743	4.9	3820	3.3	116832
	Missing	10251	33.4	6722	21.4	12069	38.3	10840	34.4	5485	17.4	5741	18.2	463	1.5	694	2.2	2057	6.5	31478

ACE, angiotensin converting enzyme; ARB, angiotensin receptor blocker; CAD, coronary artery disease; CKD, chronic kidney disease; DDP4, dipeptidyl peptidase 4 inhibitors; GLP-1, GLP-1 receptor agonists; PAD, peripheral artery disease; SGLT2i, sodium-glucose co-transporter-2 inhibitors; sMRA, steroidal mineralocorticoid receptor antagonists; UACR, urinary albumin creatinine ratio.

past 24 months rather than 12 months which may explain why results from the current study were higher.[16] Of note, absolute rates of most outcomes were consistent with data from a randomised clinical trial.[17]

Strengths and limitations of the study

This study used data from CPRD Aurum which includes a large sample size and is broadly representative of the English population. Rates of adverse outcomes (mortality, all-cause hospitalisation, CVD and renal outcomes) were also determined from linked HES and ONS death data to increase their validity.

The study relied primarily on clinician recording of measurements and diagnoses which is influenced by both healthcare resources and GP recording practices, as per routine care. Where data are not recorded the assumption was that no measurement was available. The validity of this assumption may vary between GP practices. UACR measurements were less frequently recorded than serum creatinine and we considered were likely not to be missing at random. Therefore we did not define CKD prevalence only among those with valid measures of both serum creatinine and UACR, as this could introduce bias by systematically including those with a higher probability of having CKD. However it is possible that the higher percentage of missing UACR data may have introduced measurement error and that we have underestimated CKD prevalence. Finally, there is also bias in the use of one measurement of eGFR in the past 24 months to define CKD which may have overestimated the prevalence, and we have not measured the formal definition of CKD as being determined by at least two measures of eGFR <60 mL/min at least 3 months apart, as this could have introduced survivor bias. This was a pragmatic outcome measure to maximise the study population, given the limitations of using electronic health records data not collected specifically for research purposes.

The study findings within this report are descriptive and not adjusted for confounding factors and should not be used to interpret causal relationships.

Study meaning and implications for clinicians and policymakers

In this study we have aimed to quantify the disease burden of CKD within patients with T2D and describe this patient population more broadly in terms of a wide range of clinical and demographic characteristics. We have particularly focused on patterns of medication use to assess levels of treatment and management in a real-world clinical setting. The findings, while descriptive, provide detailed information which can help clinicians in understanding this patient population better. We have shown that while recording of CKD status in the T2D populations appears to be high at least in terms of creatinine measurement, there are opportunities for improvement by more regular use of UACR testing. Our data regarding prescribing suggests there may be opportunities to increase use of evidence-based treatments within this high-risk group of

Table 6 Rate of adverse outcomes (overall mortality, all-cause hospitalisation, CVD outcomes, renal outcomes) in those with prevalent type 2 diabetes and CKD over the study period

		All-cause mortality	All-cause hospitalisation (first instance during time period)	CVD mortality	First instance hospitalisation Myocardial infarction	First instance hospitalisation Stroke	First hospitalisation Heart Failure	Composite CVD outcome (hospitalisation or death)	End stage renal failure*
		Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)	Rate per 1000 person years (95% CI)
No CKD 1 January 2017		26.7 (26.4 to 27.0)	270.7 (269.5 to 271.9)	6.7 (6.5 to 6.9)	5.0 (4.8 to 5.1)	4.1 (4.0 to 4.2)	3.7 (3.5 to 3.8)	15.1 (14.9 to 15.4)	1.0 (0.9 to 1.0)
Prevalent type 2 diabetes and CKD 1 January 2017		85.8 (84.9 to 86.7)	464.2 (461.4 to 466.9)	26.7 (26.2 to 27.2)	11.7 (11.3 to 12.0)	11.0 (10.7 to 11.3)	20.6 (20.1 to 21.1)	49.1 (48.4 to 49.9)	10.0 (9.7 to 10.4))
+Coronary artery disease	No	71.8 (70.9 to 72.8)	411.7 (408.7 to 414.6)	19.3 (18.7 to 19.8)	7.9 (7.6 to 8.2)	9.1 (8.8 to 9.5)	14.1 (13.7 to 14.5)	39.3 (38.6 to 40.1)	9.3 (8.9 to 9.6)
	Yes	128.0 (125.8 to 130.3)	661.5 (654.4 to 668.8)	49.3 (48.0 to 50.7)	27.6 (26.4 to 28.9)	14.8 (14.0 to 15.5)	42.0 (40.7 to 43.4)	95.0 (92.6 to 97.6)	12.5 (11.8 to 13.2)
+Heart failure	No	72.5 (71.6 to 73.4)	431.9 (429.1 to 434.7))	19.9 (19.4 to 20.4)	10.5 (10.2 to 10.9)	10.3 (10.0 to 10.7)	13.9 (13.5 to 14.3)	41.7 (41.0 to 42.4)	8.9 (8.6 to 9.2)
	Yes	192.9 (188.8 to 197.0)	800.8 (788.6 to 813.2)	81.9 (79.3 to 84.6)	22.9 (21.3 to 24.5)	16.6 (15.4 to 17.9)	96.6 (93.1 to 100.1)	149.0 (145.4 to 152.7)	19.4 (18.1 to 20.8)
+Hypertension	No	60.6 (58.2 to 63.2)	357.7 (350.3 to 365.3)	12.2 (11.2 to 13.4)	6.5 (5.7 to 7.3)	6.6 (5.8 to 7.5)	5.9 (5.1 to 6.7)	24.2 (22.7 to 25.9)	5.0 (4.3 to 5.8)
	Yes	88.4 (87.5 to 89.4)	476.7 (473.7 to 479.6)	28.3 (27.7 to 28.8)	12.3 (11.9 to 12.6)	11.5 (11.1 to 11.8)	22.2 (21.7 to 22.7)	52.1 (51.3 to 52.9)	10.6 (10.2 to 10.9)
+ARB/ACE-I use in past 3 months as of January 2017	No	118.1 (116.2 to 120.1)	516.9 (511.5 to 522.3)	32.0 (31.0 to 33.0)	12.2 (11.6 to 12.9)	12.8 (12.1 to 13.4)	20.4 (19.6 to 21.2)	52.9 (51.6 to 54.4)	13.0 (12.4 to 13.7
	Yes	71.7 (70.7 to 72.7)	442.2 (439.0 to 445.4)	24.5 (23.9 to 25.0)	11.4 (11.0 to 11.8)	10.3 (9.9 to 10.6)	20.7 (20.2 to 21.3)	47.4 (46.6 to 48.3)	8.8 (8.4 to 9.1)
eGFR on 1 January 2017	G1 (>90)	21.6 (20.5 to 22.8)	287.8 (282.8 to 292.9)	6.1 (5.6, 6.8)	6.1 (5.5 to 6.7)	5.2 (4.7 to 5.8)	5.4 (4.9 to 6.0)	18.7 (17.6 to 19.8)	1.7 (1.4 to 2.1)
	G2 (60–89)	65.7 (64.0 to 67.4)	430.3 (424.8 to 436.0)	19.0 (18.1 to 19.9)	10.6 (9.9 to 11.3)	10.4 (9.7 to 11.1)	15.7 (14.9 to 16.6)	42.1 (40.7 to 43.6)	3.1 (2.8 to 3.5)
	G3a (45–59)	82.4 (80.9 to 83.9)	463.5 (458.9 to 468.2)	25.1 (24.2 to 25.9)	11.3 (10.8 to 11.9)	11.5 (11.0 to 12.1)	19.1 (18.4 to 19.8)	48.5 (47.3 to 49.8)	4.4 (4.1 to 4.8)
	G3b (30–44)	134.2 (131.6 to 137.0)	592.2 (584.4 to 600.0)	43.2 (41.7 to 44.8)	14.8 (13.9 to 15.8)	14.1 (13.2 to 15.0)	34.9 (33.5 to 36.4)	73.8 (71.5 to 76.1)	13.7 (12.8 to 14.6)
	G4(15–29)	203.0 (196.8 to 209.3)	811.5 (793.2 to 830.1)	71.0 (67.3 to 74.7)	22.6 (20.5 to 25.0)	17.2 (15.4 to 19.2)	56.2 (52.8 to 59.9)	111.6 (106.3 to 117.2)	114.0 (109.0 to 119.3)
	G5 (<15)	239.3 (226.6 to 254.0)	2042.7 (1958.7 to 2130.4)	74.1 (66.9 to 82.1)	36.2 (31.0 to 42.4)	18.5 (14.9 to 22.9)	32.0 (32.0 to 43.7)	115.6 (104.8 to 127.6)	–
UACR on 1 January 2017	A1	75.4 (73.7 to 77.2)	446.6 (441.0 to 452.3)	23.3 (22.4 to 24.4)	10.6 (9.9 to 11.3)	10.3 (9.6 to 11.0)	18.6 (17.6 to 19.5)	44.5 (43.0 to 46.0)	4.4 (4.0 to 4.8)
	A2	69.6 (68.4 to 70.7)	416.4 (412.8 to 420.0)	21.5 (20.8 to 22.1)	9.9 (9.5 to 10.4)	9.7 (9.3 to 10.1)	16.5 (15.9 to 17.1)	41.1 (40.2 to 42.1)	5.1 (4.8 to 5.5)
	A3	116.9 (113.3 to 120.6)	615.1 (603.4 to 627.0)	40.3 (38.3 to 42.5)	20.7 (19.2 to 22.4)	16.0 (14.7 to 17.5)	37.2 (35.2 to 39.4)	81.6 (78.2 to 85.0)	39.4 (37.37 to 41.7)

*First incidence of eGFR <15 and/or first occurrence Read code dialysis/renal transplant (CPRD) and/or first occurrence of hospital procedure for renal disease (dialysis/renal transplant) (HES).
ACE-I, angiotensin converting enzyme-inhibitor; ARB, angiotensin receptor blocker; CKD, chronic kidney disease; CPRD, Clinical Practice Research Datalink; CVD, cardiovascular diseases; eGFR, estimated glomerular filtration rate; HES, Hospital Episode Statistics.

patients. This is particularly important given the very high rates of adverse outcomes observed in this population and the availability of evidence-based treatment options to address risk. Patients who have T2D, CKD and heart failure are at particularly high risk of adverse outcomes.

CONCLUSIONS

The prevalence of CKD among adults with T2D within a large sample of the English primary care population was approximately 30% and among this high-risk population recording of albuminuria well below guideline-recommended levels. Rates of adverse outcomes were high, suggesting a substantial public health impact. In order to assess risk it is important to measure and monitor both eGFR and UACR which will guide the appropriate use of evidence-based treatments. Further work should focus on strategies to improve treatment and management for patients with T2D and CKD in order to improve patient outcomes.

Author affiliations
[1]National Heart and Lung Institute, Imperial College London, London, UK
[2]Department of Non-Communicable Disease Epidemiology, Faculty of Epidemiology and Population Health, London School of Hygiene & Tropical Medicine, London, UK
[3]Bayer AG, Berlin, Germany
[4]Bayer plc, Reading, UK
[5]Division of Cardiovascular Sciences, University of Manchester, Manchester, UK
[6]Department of Renal Medicine, Salford Royal Hospital, Northern Care Alliance NHS Foundation Trust, Salford, UK

Acknowledgements This study is based in part on data from the Clinical Practice Research Datalink obtained under licence from the UK Medicines and Healthcare products Regulatory Agency. The data are provided by patients and collected by the National Health Service as part of their care and support. The interpretation and conclusions contained in this study are those of the authors alone.

Contributors Conception and design: JKQ, NS, JB, LAT and PK. Data analysis: SC. Data interpretation: JKQ, NS, JB, LAT, PK and SC. Drafting initial manuscript: SC. Revision of manuscript: JKQ, NS, JB, LAT, PK and SC. Guarantor SC. Final approval of the manuscript to be published: All authors. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding This study was funded by Bayer AG.

Competing interests JB is an employee of Bayer, UK. NS is now an employee at Boehringer Ingelheim International. All of his work for this project was done while an employee for Bayer AG. Imperial College London received funding on behalf of JKQ, and SC for the work. PK and LAT received funding from Bayer AG for their contributions to this project.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study was approved by Independent Scientific Advisory Committee for Medicines and Healthcare products Regulatory Agency database research (protocol number=#20_000167). This study is based in part on data from the Clinical Practice Research Datalink obtained under licence from the UK Medicines and Healthcare products Regulatory Agency. The data is provided by patients and collected by the NHS as part of their care and support. The interpretation and conclusions contained in this study are those of the author/s alone. Linked pseudonymised data was provided for this study by CPRD. Data is linked by NHS Digital, the statutory trusted third party for linking data, using identifiable data held only by NHS Digital. Select general practices consent to this process at a practice level with individual patients having the right to opt-out.This study is based in part on data from the Clinical Practice Research Datalink (CPRD) obtained under licence from the UK Medicines and Healthcare products Regulatory Agency. The data is provided by patients and collected by the National Health Service (NHS) as part of their care and support. The Office for National Statistics (ONS) was the provider of the ONS Data contained within the CPRD Data and maintains a Copyright © 2019, re-used with the permission of The Health & Social Care Information Centre, all rights reserved. The interpretation and conclusions contained in this study are those of the authors alone.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. Data are available on request from the CPRD. Their provision requires the purchase of a license, and this license does not permit the authors to make them publicly available to all. This work used data from the version collected in December 2020 and have clearly specified the data selected within each Methods section. To allow identical data to be obtained by others, via the purchase of a license, the code lists will be provided upon request and are available within the Project Github repository NHLI-Respiratory-Epi/ABC-CKD (github.com). Licenses are available from the CPRD (http://www.cprd.com): The Clinical Practice Research Datalink Group, The Medicines and Healthcare products Regulatory Agency, 10 South Colonnade, Canary Wharf, London E14 4PU.

ORCID iDs
Laurie A Tomlinson http://orcid.org/0000-0001-8848-9493
Jennifer K Quint http://orcid.org/0000-0003-0149-4869

REFERENCES

1 Gregg EW, Li Y, Wang J, *et al*. Changes in diabetes-related complications in the United States, 1990-2010. *N Engl J Med* 2014;370:1514–23.
2 Gheith O, Farouk N, Nampoory N, *et al*. Diabetic kidney disease: world wide difference of prevalence and risk factors. *J Nephropharmacol* 2016;5:49–56.
3 Tuttle KR, Bakris GL, Bilous RW, *et al*. Diabetic kidney disease: a report from an ADA consensus conference. *Diabetes Care* 2014;37:2864–83.
4 National KF. *KIDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease*. Kidney International Supplements, 2013: 3.
5 Kottgen A, Russell SD, Loehr LR, *et al*. Reduced kidney function as a risk factor for incident heart failure: the Atherosclerosis risk in communities (ARIC) study. *J Am Soc Nephrol* 2007;18:1307–15.
6 Gansevoort RT, Correa-Rotter R, Hemmelgarn BR, *et al*. Chronic kidney disease and cardiovascular risk: epidemiology, mechanisms, and prevention. *Lancet* 2013;382:339–52.
7 Jepson C, Hsu JY, Fischer MJ, *et al*. Incident type 2 diabetes among individuals with CKD: findings from the chronic renal insufficiency cohort (CRIC) study. *Am J Kidney Dis* 2019;73:72–81.
8 MacRae C, Mercer SW, Guthrie B, *et al*. Comorbidity in chronic kidney disease: a large cross-sectional study of prevalence in Scottish primary care. *Br J Gen Pract* 2021;71:e243–9.
9 Fraser SDS, Roderick PJ, May CR, *et al*. The burden of comorbidity in people with chronic kidney disease stage 3: a cohort study. *BMC Nephrol* 2015;16:193.
10 Eriksen BO, Ingebretsen OC. The progression of chronic kidney disease: a 10-year population-based study of the effects of gender and age. *Kidney Int* 2006;69:375–82.
11 Afkarian M, Sachs MC, Kestenbaum B, *et al*. Kidney disease and increased mortality risk in type 2 diabetes. *J Am Soc Nephrol* 2013;24:302–8.
12 Groop P-H, Thomas MC, Moran JL, *et al*. The presence and severity of chronic kidney disease predicts all-cause mortality in type 1 diabetes. *Diabetes* 2009;58:1651–8.

13 Department oH. Turning the corner: improving diabetes care. 2006. Available: https://webarchive.nationalarchives.gov.uk/ukgwa/20130123210127/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_4136141
14 Wolf A, Dedman D, Campbell J, *et al*. Data resource profile: clinical practice research datalink (CPRD) aurum. *Int J Epidemiol* 2019;48:1740g.
15 Matsushita K, van der Velde M, Astor BC, *et al*. Association of estimated glomerular filtration rate and albuminuria with all-cause and cardiovascular mortality in general population cohorts: a collaborative meta-analysis. *Lancet* 2010;375:2073–81.
16 Nitsch D, Caplin B, Hull S, *et al*. National chronic kidney disease audit//national report (part 1) january 2017. 2017. Available: https://www.lshtm.ac.uk/files/ckd_audit_report.pdf
17 Bakris GL, Agarwal R, Anker SD, *et al*. Effect of finerenone on chronic kidney disease outcomes in type 2 diabetes. *N Engl J Med* 2020;383:2219–29.