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A retrospective cohort study predicting and validating impact of the COVID-19 pandemic in individuals with chronic kidney disease

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Chronic kidney disease (CKD) is associated with increased risk of baseline mortality and severe COVID-19, but analyses across CKD stages, and comorbidities are lacking. In prevalent and incident CKD, we investigated comorbidities, baseline risk, COVID-19 incidence, and predicted versus observed one-year excess death. In a national dataset (NHS Digital Trusted Research Environment [NHSD TRE] for England encompassing 56 million individuals), we conducted a retrospective cohort study (March 2020 to March 2021) for prevalence of comorbidities by incident and prevalent CKD, SARS-CoV-2 infection and mortality. Baseline mortality risk, incidence and outcome of infection by comorbidities, controlling for age, sex and vaccination were assessed. Observed versus predicted one-year mortality at varying population infection rates and pandemic-related relative risks using our published model in pre-pandemic CKD cohorts (NHSD TRE and Clinical Practice Research Datalink [CPRD]) were compared. Among individuals with CKD (prevalent:1,934,585, incident:144,969), comorbidities were common (73.5% and 71.2% with one or more condition[s] in respective data sets, and 13.2% and 11.2% with three or more conditions, in prevalent and incident CKD), and associated with SARS-CoV-2 infection, particularly dialysis/transplantation (odds ratio 2.08, 95% confidence interval 2.04-2.13) and heart failure (1.73, 1.71-1.76), but not cancer (1.01, 1.01-1.04). One-year all-cause mortality varied by age, sex, multi-morbidity and CKD stage. Compared with 34,265 observed excess deaths, in the NHSD-TRE and CPRD databases respectively, we predicted 28,746 and 24,546 deaths (infection rates 10% and relative risks 3.0), and 23,754 and 20,283 deaths (observed infection rates 6.7% and relative risks 3.7). Thus, in this largest, national-level study, individuals with CKD have a high burden of comorbidities and multi-morbidity, and high risk of pre-pandemic and pandemic mortality. Hence, treatment of comorbidities, non-pharmaceutical measures, and vaccination are priorities for people with CKD and management of long-term conditions is important during and beyond the pandemic.

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KEYWORDS: chronic kidney disease; mortality; SARS-CoV-2

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Chronic kidney disease (CKD) carries major global disease burden, as a risk factor for morbidity and mortality, and as the end syndrome of underlying risk factors and diseases,1,2 such as cancers3 and cardiovascular disease (CVD).4 During the coronavirus disease 2019 (COVID-19) pandemic, CKD has been associated with poor prognosis.5–8 Despite clinical and public health importance, CKD research to date in all stages, multimorbidity, or the general population6–8 using national-level data has been limited. The pandemic has had both direct (through infection) and indirect (through changes in health services, economic upheaval, and behavioural factors8,9) impacts. The direct impact in individuals with CKD and other underlying conditions is related to baseline risk, influenced by age, sex, multi-morbidity, and other sociodemographic factors.10 However, previous studies of COVID-19 in CKD have been small scale (12–1099 cases1), have mostly focused on end-stage CKD, and have ignored major comorbidities (either most common in CKD or related to risk of COVID-19 mortality). Few risk
stratification tools are used in clinical practice for individuals with CKD or prediction of CKD, and those that include CKD usually do not consider different CKD stages. Better characterization of baseline risk in people with CKD may inform individual and population approaches to CKD prevention and treatment and integrated management of chronic diseases.

CKD, already known to increase baseline risk of mortality, is associated with increased risk of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection, disease severity, hospitalization, intensive care admission, and mortality. The role of other risk factors and underlying conditions in risk of COVID-19 in people with CKD requires more detailed investigation. There are clinical practice tools for risk stratification of COVID-19 patients in the community and hospitals, but inclusion of CKD is as a binary variable, and the spectrum of risk faced by individuals with CKD has not been fully considered. Such analyses are important in risk communication to patients, public and health professionals, as well as policies to suppress infection rate (IR), such as social distancing and physical isolation. Meanwhile, more nuanced investigation of the risk associated with CKD may inform clinical care, COVID-19 vaccination strategies, as well as public health approaches to CKD after the pandemic.

Using national, population-based electronic health records (EHRs), in individuals with prevalent and incident CKD, we investigated the following: (i) underlying conditions; (ii) mortality risk; (iii) incidence of SARS-CoV-2 infection, and (iv) prediction and validation of pandemic-related excess deaths.

**METHODS**

**Study design and data sources**

We conducted a retrospective, population-based cohort study using NHS Digital Trusted Research Environment for England (NHSD TRE), a national database developed for pandemic-related research, linking primary care, 

**Statistical analysis**

### Underlying conditions

We estimated prevalence of underlying conditions in prevalent CKD, stratifying by age, gender, CKD stage, or dialysis/transplantation. We compared prevalence of underlying conditions in infected versus noninfected for (i) all CKD patients and (ii) nonsurvival group, using odds ratio (Wald method) and Mantel-Haenszel χ² test with 95% confidence intervals.

### Mortality risk

With SARS-CoV-2 infection as exposure and 1-year all-cause mortality as outcome, we estimated adjusted relative risk (RR), stratified by underlying conditions, for both prevalent and incident CKD, using generalized linear model with Poisson distribution (log link) after adjusting for the following: (i) age and (ii) age and other potential confounders by exact matching based on ≥1 vaccination dose, age groups (5-year intervals), and sex, assessing matching quality using distributional plots. To estimate overall effect of having an underlying condition, analyses were repeated with generalized linear model for each condition, reporting respective RRs (with “SARS-CoV-2 positive” as another potential confounder in exact matching).

### Incidence of SARS-CoV-2 infection

We estimated crude incidence rate of SARS-CoV-2 infection per 10,000 person-week, stratified by underlying conditions for incident and prevalent CKD.

### Predicting and validating pandemic-related excess deaths

By Kaplan-Meier analyses, we estimated prepandemic baseline risk of 1-year all-cause mortality for prevalent CKD in NHSD TRE (2019) and CPRD cohorts (2014). We validated our
recent model\textsuperscript{14,15} (to predict COVID-19–related excess death) using our risk estimates and applying 1-year population IR of 10%, and overall RR of mortality (set at 3) based on previous reports.\textsuperscript{15,26} We predicted total excess deaths by: (i) age groups and number of underlying conditions and (ii) underlying conditions, using assumed and observed IR and RR. The analysis was performed according to a prespecified analysis plan published on GitHub (https://github.com/BHFDSC/CCU003_01), including implementations and phenotypes.

Role of the funding source
The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. AD, MAM, and AB had full access to all the data in the study; and AB had final responsibility for the decision to submit for publication.

RESULTS

Overall population characteristics
We included 1,934,585 individuals with prevalent CKD (mean age, 77.4 ± 12 years; 58.0% female; 12.7% CKD stage >3; 4.4% dialysis/transplantation) and 144,169 with incident CKD (mean age, 73.9 ± 12.8 years; 51.9% female; 9.2% CKD stage >3; 2.4% dialysis/transplantation; Supplementary Figure S1 and Supplementary Tables S2 and S3). Among those with prevalent and incident CKD, 91.5% and 86.6%, respectively, were aged >60 years, and 48.0% and 36.1%, respectively, were aged >80 years. In the first year of the pandemic, in those with prevalent and incident CKD, 6.7% and 7.8% were infected, 1.8% and 1.7% had died from COVID-19, and 8.9% and 7.0% had died from all causes, respectively.

Underlying conditions
Comorbidities were more common in prevalent than incident CKD, and in males, in older individuals, and at CKD stages 4 and 5, especially CVD (prevalent CKD vs. incident CKD, 42.5% vs. 39.6%) and diabetes (prevalent CKD vs. incident CKD, 30.5% vs. 28.8%; Supplementary Figures S2–S5). Looking at comorbidity pairs, the most common combinations were 2 CVD subtypes (e.g., 20.5% for atrial fibrillation and CVD), diabetes with CVD (15.3%), and cancer with CVD (11.6%) in prevalent CKD (Supplementary Figure S2). A total of 73.5% and 13.2% of individuals with prevalent CKD and 71.2% and 11.2% of those with incident CKD had ≥1 and ≥3 underlying conditions, respectively (Supplementary Tables S2 and S3). SARS-CoV-2 infection rates were higher in incident than prevalent CKD (e.g., 39.2 vs. 28.1 per 10,000 person-weeks for chronic liver disease, 37.9 vs. 25.8 for stage 5 CKD, 31.7 vs. 24.1 for heart failure; Figure 1). Comorbidities were associated with infection, compared with noninfected individuals, particularly for dialysis/transplantation (odds ratio [OR], 2.08; 95% confidence interval [CI], 2.04–2.13) and heart failure (OR, 1.73; 95% CI, 1.71–1.76), but not for cancer (OR, 1.01; 95% CI, 1.01–1.04). Across all comorbidities, association with infection was reduced in the nonsurviving group. Cancer (OR, 0.80; 95% CI, 0.78–0.82), atrial fibrillation (OR, 0.90; 95%...
Table 1 | Association between SARS-CoV-2 infection and 1-year mortality by underlying condition for prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease

| Underlying conditions | Dialysis/transplantation | Chronic liver disease |
|-----------------------|--------------------------|-----------------------|
| Method                | COPD | Asthma | PAD | Heart failure | Atrial fibrillation | Diabetes mellitus | CVD | Cancer |
| Prevalent             |      |       |     |              |                  |                     |     |        |
| AS                    | 2.63 (2.57–2.69) | 3.01 (2.93–3.09) | 2.67 (2.57–2.77) | 2.25 (2.21–2.30) | 2.35 (2.31–2.40) | 3.11 (3.06–3.17) | 2.59 (2.56–2.63) | 2.70 (2.64–2.75) | 2.41 (2.30–2.52) | 2.09 (1.88–2.31) |
| M                     | 1.15 (1.13–1.17) | 1.27 (1.24–1.30) | 1.16 (1.12–1.19) | 1.14 (1.10–1.16) | 1.12 (1.10–1.13) | 1.32 (1.30–1.33) | 1.19 (1.17–1.20) | 1.13 (1.11–1.15) | 1.18 (1.13–1.22) | 1.07 (0.99–1.17) |
| Incident              |      |       |     |              |                  |                     |     |        |
| AS                    | 3.04 (2.77–3.34) | 3.58 (3.21–3.97) | 3.63 (3.05–4.29) | 2.69 (2.48–2.91) | 2.98 (2.76–3.21) | 3.66 (3.40–3.93) | 3.08 (2.91–3.26) | 3.04 (2.80–3.31) | 1.54 (1.23–1.90) | 1.26 (0.87–1.76) |
| M                     | 1.13 (1.04–1.21) | 1.31 (1.21–1.42) | 1.25 (1.10–1.42) | 1.14 (1.07–1.22) | 1.15 (1.09–1.22) | 1.38 (1.30–1.45) | 1.20 (1.15–1.23) | 1.15 (1.07–1.22) | 0.90 (0.75–1.07) | 0.85 (0.62–1.15) |

AS, adjusting for age and sex; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; M, adjusting for age, sex, and vaccination using exact matching; PAD, peripheral arterial disease; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

Data are given as relative risk (95% confidence interval).
Table 2 | Estimated 1-year excess deaths by population infection rate and relative impact of the pandemic using *Lancet* 2020 model\(^{22,23}\) and prevalent CKD patients in 2 independent population-based cohorts (NHSD TRE and CPRD)

| Data used in *Lancet* 2020 model (date of analysis of prevalent CKD) | RR of mortality associated with the pandemic | Population infection rate, % | Assumed | Observed* |
|---|---|---|---|---|
| NHSD TRE (January 1, 2019) | Assumed 1.5 | 10 | 14,373 (41.9) | 20,283 (59.2) |
| | | 40 | 57,492 (167.8) | 20,283 (59.2) |
| | | 80 | 114,984 (335.6) | 20,283 (59.2) |
| | Assumed 2 | 10 | 19,164 (55.9) | 20,283 (59.2) |
| | | 40 | 76,656 (223.7) | 20,283 (59.2) |
| | | 80 | 153,312 (447.4) | 20,283 (59.2) |
| | Assumed 3 | 10 | 28,746 (83.9) | 20,283 (59.2) |
| | | 40 | 114,984 (335.6) | 20,283 (59.2) |
| | | 80 | 229,968 (671.1) | 20,283 (59.2) |
| CPRD (April 6, 2014) | Observed\(^{a}\) 3.7 | 10 | 35,453 (103.5) | 24,546 (71.6) |
| | | 40 | 141,812 (413.9) | 98,184 (286.5) |
| | | 80 | 283,624 (827.7) | 196,368 (573.1) |
| | Assumed 1.5 | 10 | 12,273 (35.8) | 20,283 (59.2) |
| | | 40 | 49,092 (143.3) | 20,283 (59.2) |
| | | 80 | 98,184 (286.5) | 20,283 (59.2) |
| | 2 | 16,364 (47.8) | 20,283 (59.2) |
| | | 40 | 65,456 (191) | 20,283 (59.2) |
| | | 80 | 130,912 (382.1) | 20,283 (59.2) |
| | Assumed 3 | 10 | 24,546 (71.6) | 20,283 (59.2) |
| | | 40 | 98,184 (286.5) | 20,283 (59.2) |
| | | 80 | 196,368 (573.1) | 20,283 (59.2) |

CKD, chronic kidney disease; CPRD, Clinical Practice Research Datalink; NHSD TRE, NHS Digital Trusted Research Environment for England; RR, relative risk.

*Observed parameters in NHSD TRE data.

The values in parentheses show percentages of observed excess deaths (i.e., 34,265). Bold data denote model using RR = 3.0 and population infection rate = 10%. Bold and italicized data denote RR = 3.7 and population infection rate = 6.7%.

( Supplementary Table S8). Prepandemic 1-year all-cause mortality in the CPRD cohort (Supplementary Figure S9) was comparable to the NHSD TRE cohort, by number of underlying conditions, age, sex, and CKD stage.

Using NHSD TRE and CPRD data, our model predicted 28,746 (83.9%) and 24,546 (71.6%) deaths, respectively, with IR of 10% and RR of 3.0, and 23,754 (69.3%) and 20,283 (59.2%) deaths, respectively, with IR of 6.7% and RR of 3.7, compared with 34,265 observed excess deaths (Table 2). For NHSD TRE data, the prediction of COVID-19 deaths was significantly improved using IR of 10% and RR of 3.0, compared with IR of 6.7% and RR of 3.7 (e.g., 90.6% vs. 71.2% for chronic obstructive pulmonary disease, 94.4% vs. 74.2% for heart failure, and 90.3% vs. 71.0% for cancer). The model underpredicted for asthma (77.0% vs. 60.5%) and diabetes (76.0% vs. 59.7%) and overpredicted for dialysis/transplantation (124.3% vs. 97.7%; Table 3). The predicted proportions of COVID-19 deaths by age group were comparable to the observed proportions, for both NHSD TRE and CPRD data (Supplementary Figure S10) (e.g., in individuals aged >80 years, observed 75.0% and predicted 73.8% using NHSD TRE data and 76.6% using CPRD data).

**DISCUSSION**

In this large, nationally representative cohort study of individuals with CKD, we had 4 findings. First, comorbidities and multimorbidity were common, and associated with SARS-CoV-2 infection and severe COVID-19. Second, 1-year mortality risk was high and dependent on age, underlying condition, stage of CKD, and incidence or prevalence of CKD, ranging from 0.5% to 37.2%. Third, the UK burden of COVID-19 excess deaths in individuals with CKD was >34,000 in 1 year and predictable using a simple, parsimonious model and routine EHRs. Fourth, we showed that vaccination was associated with reduced mortality risk.

Diabetes and CVD are well documented as major risk factors and comorbidities in people with CKD, whether in epidemiologic\(^ {27,28}\) or therapeutic research.\(^ {29}\) We describe, for the first time, distribution of comorbidities and multimorbidity across the whole spectrum of CKD, both prevalent and incident CKD in up-to-date national data for England. These data are important for planning services for treatment and prevention in individuals with CKD both during and after the pandemic. For example, 7% of individuals with incident or prevalent CKD have both diabetes and cancer; >10% have CVD and cancer. Projections of direct and indirect impact of COVID-19 have not considered overlap between diseases and treatments, probably leading to underestimation. Our finding of higher infection rates in those with dialysis/transplantation may be related to detection bias due to some regular monitoring of those patients for COVID-19 symptoms, resulting in a better detection of SARS-CoV-2 infection. In this context, developing a new condition (such as incident CKD) could potentially increase the contacts with health service that could have resulted in higher detection of infection in incident CKD than prevalent CKD. Despite that, the low rates observed for cancer patients could be related to shielding strategy in clinically vulnerable patients in the United Kingdom. Our results are in line with prior studies\(^ {13}\) showing higher infection rates in those with CKD. Future research should also address subtypes of CKD and trajectory by comorbidity profile to guide and prioritize preventive clinical and public health interventions.

We provide detailed large-scale, population-based analyses to provide patients, health professionals, and policy makers with understanding of pre–COVID-19 and post–COVID-19 mortality risk in people with CKD, based on age, underlying conditions, and incident versus prevalent diseases. Despite increasing clinical, societal, and scientific interest in precision medicine, CKD has not been comprehensively investigated, whether in terms of etiology, prognosis, or prevention research.\(^ {1,2,28}\) Such granular, personalized data can inform risk prediction and public health projections to translational research and conversations with patients about individual
risk. Moreover, such approaches are needed to help future research in long COVID-19.

Excess deaths have been the main metric to measure direct and indirect COVID-19 impact, whether overall or in individuals with particular diseases. We present the first analyses in individuals with CKD. These are projections over 1 year based on a published model and consistent with analyses in individuals with CKD. These are projections over 1 year based on a published model and consistent with analyses in individuals with particular diseases. We present the first analyses in individuals with CKD. These are projections over 1 year based on a published model and consistent with analyses in individuals with CKD. These are projections over 1 year based on a published model and consistent with analyses in individuals with particular diseases.

Table 3 | Observed and predicted excess deaths (due to COVID-19) by underlying conditions over 1 year of the pandemic in individuals with prevalent chronic kidney disease (n = 1,934,585)

| COVID-19 deaths | COPD | Asthma | Heart failure | Atrial fibrillation | Diabetes | CVD | Cancer | Dialysis/ transplantation | Total excess death |
|-----------------|------|--------|---------------|--------------------|----------|-----|--------|------------------------|-----------------|
| Observed        | 7890 | 6822   | 11,394        | 12,166             | 14,617   | 22,839 | 9979   | 2043                   | 34,265 (100.0)  |
| Predicted, using assumed IR of 10%/RR of 3.0 (% predicted/observed) | 7152 (90.6) | 5251 (77) | 10,758 (94.4) | 11,706 (96.2) | 11,114 (76.0) | 20,104 (87.6) | 9011 (90.3) | 2539 (124.3) | 28,746 (83.9) |
| Predicted, using observed IR of 6.7%/RR of 3.7 (% predicted/observed) | 5621 (71.2) | 4126 (60.5) | 8453 (74.2) | 9199 (75.6) | 8732 (59.7) | 15,726 (68.9) | 7081 (71.0) | 1997 (97.7) | 23,754 (69.3) |

COPD, chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; CVD, cardiovascular disease; IR, infection rate; RR, relative risk (of COVID-19 pandemic compared with baseline).

Assumed IR/RR is based on Lancet 2020 model (Banerjee et al.15). Observed IR/RR was observed during pandemic in individuals with chronic kidney disease.

Implications for research and policy

There are 3 policy implications. First, our findings are consistent with a “syndemic,” describing convergence of an recent meta-analysis (16 [95% CI, 4–33] per 10,000 person weeks).
infectious disease, undertreated noncommunicable diseases, and social determinants of health, requiring multidisciplinary, rather than traditional, disease- and specialty-specific responses. Second, given high comorbidity burden, particularly CVD and cancer, it is important to mitigate against indirect effects, likely to disproportionately affect people with CKD. Third, routine data can provide patients, public, professionals, and policy makers with tailored risk information because mortality is highly variable based on age, sex, multimorbidity, and disease stage, which can inform prepanemic and pandemic management, such as social isolation policies and vaccination prioritization in individuals with CKD.

There are 3 research implications. First, clustering approaches may inform and clarify subtype classification, trajectories, and risk prediction in CKD. Second, possible mechanisms underlying observed differences in mortality by age, comorbidities, ethnicity, stage of CKD, and other factors need investigation. Third, pathophysiology of CKD as a risk factor and an outcome in COVID-19 warrants further study, informing etiology, prevention, and intervention research.

Conclusions
In conclusion, individuals with CKD have high burden of multimorbidity and high risk of prepanemic mortality across all stages of CKD and in prevalent and incident disease. We showed that the direct burden of pandemic could be predicted using prepanemic, large-scale EHR data. The combined data for multimorbidity, CKD stage, and age could help prioritize patients for vaccination and post–COVID-19 policies, and design of stratified pathways for CKD patients.

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Approval for the study was granted by the Independent Scientific Advisory Committee (20_074R) of the Medicines and Healthcare Products Regulatory Agency in the United Kingdom in accordance with the Declaration of Helsinki. The North East-Newcastle and North Tyneside 2 research ethics committee provided ethical approval for the CVD-COVID-UK/COVID-IMPACT research programme (REC 20/NE/
0161) to access, within secure trusted research environments, unconsented, whole-population, de-identified data from electronic health records collected as part of patients’ routine health care.

**AUTHOR CONTRIBUTIONS**

AB conceived the research question. AB, JBM, and TM obtained funding. AB and AD designed the study and analysis plan. SD, CS, and the BHF Data Science Centre CVD-COVID-UK/COVID-IMPACT consortium prepared the data, including electronic health record phenotyping in the CALIBER open portal. CS is the Director of the BHF Data Science Centre and coordinated approvals for and access to data within the NHS Digital Trusted Research Environment for England (TRE) for CVD-COVID-UK/COVID-IMPACT. AD prepared the chronic kidney disease (CKD) cohorts (including phenotyping of CKD stages), designed incidence study, and performed statistical analysis. MAM provided all required implementations for adding phenotypes, and vaccination data in TRE, beside insightful comments throughout research. AB and AD drafted the initial and final versions of the manuscript. All authors critically reviewed early and final versions of the manuscript.

**SUPPLEMENTARY MATERIAL**

Supplementary File (Word)

**Figure S1.** Study population of prevalent and incident chronic kidney disease in England (NHS Digital Trusted Research Environment for England [NHSD TRE] data for England).

**Figure S2.** Prevalence and co-occurrence of underlying conditions in individuals with prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease in national data for England (NHS Digital Trusted Research Environment for England [TRE]: March 1, 2020, to March 1, 2021).

**Figure S3.** Underlying conditions by age, sex, and chronic kidney disease (CKD) stage in individuals with prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease in NHS Digital Trusted Research Environment for England (NHSD TRE).

**Figure S4.** Prevalence of underlying conditions by age group, chronic kidney disease (CKD) stage, and sex, in individuals with prevalent (n = 1,934,585) and incident (n = 144,969) CKD during the coronavirus disease 2019 (COVID-19) pandemic.

**Figure S5.** Association between severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection and underlying conditions in individuals with chronic kidney disease (CKD) in (A) all prevalent CKD (n = 1,934,585) and (B) the nonsurvival group (i.e., those not surviving to 1-year follow-up during pandemic; n = 172,789).

**Figure S6.** One-year all-cause mortality (percentage) in individuals with prevalent (n = 1,934,585) chronic kidney disease (CKD) by number of underlying conditions, age, sex, and CKD stage, using Clinical Practice Research Datalink (CPRD) data on April 6, 2014.

**Figure S7.** Covariate balance before and after exact matching for prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease, using standardized mean difference in all individuals and those with cancer, diabetes, and dialysis/transplantation.

**Figure S8.** Observed age-specific, unadjusted relative risk of mortality and population infection rate during first year of coronavirus disease 2019 (COVID-19) pandemic in individuals with prevalent chronic kidney disease (n = 1,934,585).

**Figure S9.** Preparademic 1-year all-cause mortality (percentage) in individuals with prevalent (n = 174,648) chronic kidney disease (CKD) by number of underlying conditions, age, sex, and CKD stage, using Clinical Practice Research Datalink (CPRD) data on April 6, 2014.

**Figure S10.** Proportion of excess coronavirus disease 2019 (COVID-19) deaths in individuals with prevalent chronic kidney disease by age group during 1 year of pandemic, predicted by Lancet 2020 model (population infection rate, 10%; relative risk, 3) using preparademic study population in NHS Digital Trusted Research Environment for England (NHSD TRE; predicted n = 28,746) and Clinical Practice Research Datalink (CPRD; predicted n = 24,546), compared with actual excess deaths (observed n = 34,265).

**Table S1.** Code list used to identify chronic kidney disease in primary and secondary care, including International Classification of Diseases, Tenth Revision (ICD-10), codes and SNOMED CT concepts.

**Table S2.** Baseline characteristics in individuals with prevalent chronic kidney disease (CKD; n = 1,934,585) at the onset of and during coronavirus disease 2019 (COVID-19) pandemic (from March 1, 2020): age, sex, stages of CKD, underlying conditions, and COVID-19 mortality.

**Table S3.** Baseline characteristics of incident (n = 144,969) chronic kidney disease (CKD) during coronavirus disease 2019 (COVID-19) pandemic (March 1, 2020, to March 1, 2021): age, sex, stages of CKD, underlying conditions, and 28-day COVID-19 mortality.

**Table S4.** Association between underlying conditions and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection (compared with noninfected individuals) in individuals with chronic kidney disease (CKD) in (A) all prevalent (n = 1,934,585) or incident CKD (n = 144,969) and (B) the nonsurvival group (i.e., those not surviving to 1-year follow-up during pandemic; n = 172,789).

**Table S5.** Association between underlying conditions and 1-year all-cause mortality for prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease.

**Table S6.** Association between coronavirus disease 2019 (COVID-19) vaccination and 1-year all-cause mortality by underlying condition for prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease.

**Table S7.** Incidence rate of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection per 10,000 person-weeks in prevalent (n = 1,934,585) and incident (n = 144,969) chronic kidney disease (CKD) over 1 year of the coronavirus disease 2019 (COVID-19) pandemic: (A) crude and (B) adjusted based on first COVID-19 vaccination, underlying conditions, and CKD stage.

**Table S8.** Baseline characteristics of preparademic prevalent chronic kidney disease (CKD) in the NHS Digital Trusted Research Environment for England (NHSD TRE; n = 1,727,130; January 1, 2019) and Clinical Practice Research Datalink (CPRD; n = 174,648; April 1, 2014) by age, sex, stages of CKD, and underlying conditions.

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