

1 **The association between coding for chronic kidney disease**
2 **and kidney replacement therapy incidence at CCG-level in**
3 **England: An ecological study**

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1 **ABSTRACT**

2 **Background**

3 With ageing of the population both prevalence of chronic kidney disease (CKD) and incidence
4 of kidney replacement therapy (KRT) are rising. Existing research suggests that Read-coding
5 for CKD in those affected is associated with better implementation of recommended care and
6 fewer hospitalisations for heart failure.

7 **Aim**

8 To investigate whether coding for CKD is associated with regional KRT incidence in England.

9 **Design & setting**

10 This is an ecological study using the clinical commissioning groups (CCG) in England as
11 geographical units.

12 **Method**

13 KRT incidence rates were calculated using UK Renal Registry (UKRR) data from 01/2019 to
14 12/2021. Data on the percentage of uncoded CKD patients (PUCP) who had laboratory
15 evidence of CKD but lacked a diagnostic code were obtained from the CVDPREVENT Audit,
16 a national audit that extracts routinely held general practitioner data. Data on confounders and
17 acute kidney injury (AKI) mortality as a marker for population frailty were obtained from
18 CVDPREVENT and the UKRR, respectively. Poisson models assessed the association
19 between PUCP and KRT incidence.

20 **Results**

21 After adjusting, the PUCP was non-linearly associated with KRT incidence, with the CCGs in
22 the lowest PUCP quintile having a lower KRT incidence than the others. There was evidence
23 that this association was more pronounced in CCGs with high AKI mortality compared to CCGs
24 with low AKI mortality.

25 **Conclusion**

26 At the geographical level in England, the data suggests that the prevalence of not having
27 formally diagnosed CKD is non-linearly associated with a higher KRT incidence rate,
28 especially in areas with a high AKI mortality.

29

1 **Keywords**

2 acute kidney injury, chronic kidney disease, ecological study, kidney replacement therapy,
3 noncommunicable diseases, primary health care

4 **How this fits in**

5 Due to the long period without symptoms, chronic kidney disease (CKD) is often recognised
6 (too) late and not treated adequately. It has been shown that adding a read code for CKD in
7 the GP setting when there was laboratory evidence of CKD was associated with a higher
8 quality of care for these patients and led, for example, to fewer cardiovascular diseases. This
9 study shows that adding a Read-code may also be associated with lower kidney replacement
10 therapy (KRT) incidence at a geographical level in England. These associations could be used
11 to project future regional KRT needs.

1 INTRODUCTION

2 Chronic kidney disease (CKD) is characterised by a progressive loss of kidney function. CKD
3 patients are at a much higher risk of developing other life-threatening diseases due to the
4 crucial role of kidneys in maintaining bodily homeostasis (1,2). In the UK, the estimated
5 prevalence of CKD stages 3-5 in the adult population is ~5-7% (3,4). Notably, CKD is
6 associated with costs of 1.45 billion pounds or 1.3% of all National Health Service (NHS)
7 expenditure in the UK (5).

8 Early diagnosis of CKD, and subsequent holistic treatment can slow down the loss of kidney
9 function and prevent complications. In the UK, there are pay-for-performance targets in
10 primary care for appropriately diagnosing and managing chronic diseases, including
11 hypertension, diabetes, and CKD stages 3-5 (6). Despite this, up to 30% of patients with
12 laboratory evidence of CKD were not appropriately Read-coded in primary care, with large
13 differences between individual practices (3,7–9).

14 Adding a Read-code for CKD to those with biochemical evidence of CKD stages 3-5 is a
15 marker of general practitioner (GP)-awareness, and is positively associated with better
16 cardiovascular risk management in those with CKD, as well as better coding of hypertension
17 and diabetes and negatively associated with deprivation (7,8,10–12). At the population level,
18 the percentage of patients with laboratory-based CKD who have been appropriately coded in
19 primary care can be considered a quality marker for the care of CKD patients. In prospective
20 analyses, patients with a CKD stage 3-5 Read-code had fewer cardiovascular and heart failure
21 hospitalisations, AKI episodes, and lower mortality than those uncoded with the same level of
22 kidney function (9,13).

23 A small subset of people with CKD will progress to kidney failure (KF), at which point a Kidney
24 Replacement Therapy (KRT) in the form of dialysis or transplantation is required. In England,
25 there are large regional differences in the crude KRT incidence rates, ranging from 85 to
26 214/1,000,000 in different areas of England. Even after standardisation by age and sex, there
27 was still a large variability in the rates (14). Data are conflicting on whether CKD prevalence
28 is associated at country-level with KRT incidence (15). This mismatch of regional CKD
29 prevalence with regional KRT incidence may be explained by the start of KRT not always being
30 planned, sometimes patients start dialysis after developing severe acute kidney injury (AKI).
31 AKI is more common in people with CKD, and especially in those who are not coded for CKD
32 (3). AKI is also associated with a higher risk of multimorbidity, death or serious diseases,
33 especially in more severe stages (16). It has been shown that frail people are more likely to
34 die from an AKI episode (17). Against this background, AKI mortality at the population level
35 can be seen as a marker for the underlying population frailty.

1 Notably, the COVID-19 pandemic had a massive impact on the KRT incidence, with a
2 decrease of 8.6% from 2019 to 2020 in the UK after a slight upward trend beforehand (18).
3 Despite COVID-19 being associated with a high risk of developing AKI, which can lead to a
4 significant decrease in kidney function, the recent drop in KRT incidence can potentially be
5 explained by older frail patients dying during the pandemic. As a result, trends in KRT
6 incidence become unpredictable due to the lack of sufficient longitudinal data following the
7 COVID-19 pandemic.

8 Due to the structural, financial and personnel efforts regarding KRT, the planning process
9 requires estimates of the future development of KRT incidence. Before the COVID-19
10 pandemic, these figures could be extrapolated from previous years (19). However, this is no
11 longer possible due to the massive impact of the pandemic on the CKD population (18).

12 We carried out a cross-sectional ecological study to investigate the association between the
13 percentage of uncoded CKD patients (PUCP), readily available from an ongoing primary care
14 audit, and KRT incidence (2019-2021) at the regional level of clinical commissioning groups
15 (CCG) in England. If there is an association at the regional level, it may be possible to project
16 future regional KRT incidences using longitudinal data on these metrics. Because the data for
17 KRT incidence include the pandemic period, it is further hypothesized that the association
18 between PUCP and KRT incidence at CCG level in England varies depending on the frailty of
19 the population within a given CCG, using AKI mortality at CCG level as a proxy for frailty.

1 **METHODS**

2 **Study design**

3 This ecological cross-sectional study focuses on the 106 clinical commissioning groups (CCG)
4 in England, which serve as the geographical units. CCGs were NHS bodies that organised
5 health care in the respective regions during the period in which the data for this study was
6 collected and the data were analysed in line with how they were generated in clinical care at
7 that time. As part of the restructuring in 2022, CCGs are now referred to as Sub-ICB
8 (Integrated Care Boards) Locations.

9 The study included only adult patients aged 18 and older. Only pre-existing and aggregated
10 data at CCG level were used.

11 **Data sources**

12 Population denominator data to calculate prevalences/incidences were obtained from the
13 Cardiovascular Disease Prevention (CVDPREVENT) Audit.

14 The outcome was the incidence of KRT in the CCGs, defined as initiating dialysis or kidney
15 transplantation as the first treatment without prior dialysis. The data was provided by the UK
16 Renal Registry (UKRR). Patients who received dialysis for fewer than 90 days were omitted.
17 The coverage was 100% across all CCGs. Due to the small number of events in each CCG,
18 the aggregated numbers for the three years 01/2019 to 12/2021 were used to calculate the
19 average yearly incidence.

20 The exposure was the percentage of patients in the CCGs who met the laboratory criterion for
21 CKD stage 3 or higher but had no GP-recorded CKD code. The CVDPREVENT Audit provided
22 the data up to 03/2021.

23 Covariates were included to assess potential confounding or mediation of the association
24 between exposure and outcome. All covariate data were used at CCG level. An overview and
25 more information on all data used and their sources can be found in Supplemental Table 1
26 and the Supplemental Methods.

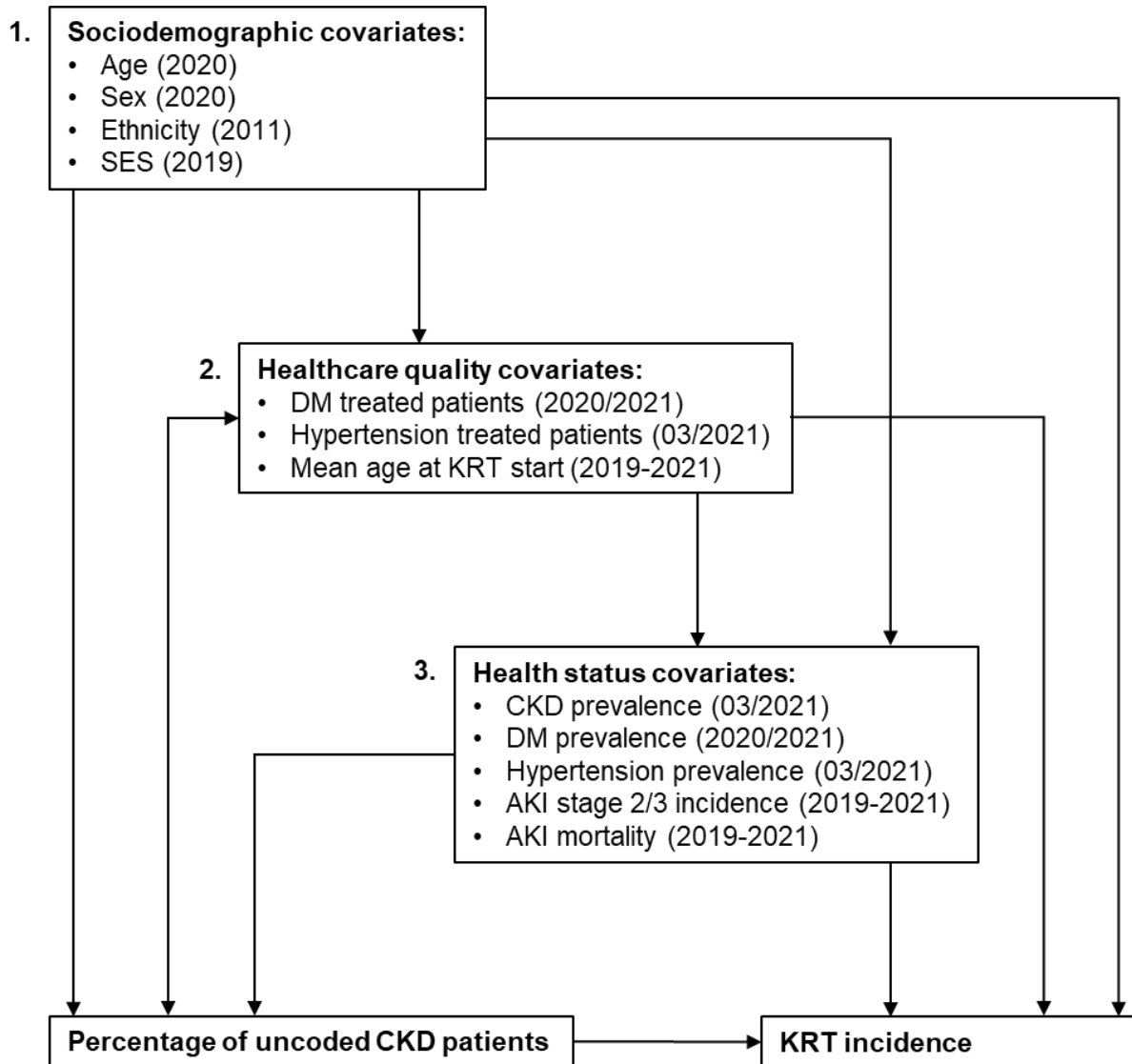
27 There were no missing data.

28 **Conceptual framework**

29 A hierarchical conceptual framework was developed to assess the association between
30 exposure and outcome (Figure 1). At CCG level, covariates could be grouped into
31 **sociodemographic, healthcare quality** and **health status covariates** and accordingly, three
32 hierarchies were considered for multivariable modelling.

1

2 **Figure 1: Hierarchical conceptual framework with three hierarchies of covariates**
3 **influencing the association between PUCP and KRT incidence**



4 In parentheses is the time up to which/period when the data was collected. *AKI Acute kidney*
5 *injury; CKD Chronic kidney disease; DM Diabetes mellitus; KRT Kidney replacement therapy;*
6 *SES Socioeconomic status.*

7 **Analysis strategy**

8 KRT incidence was categorised into quintiles with care taken to ensure that CCGs were evenly
9 distributed across the quintiles.

10 Correlation matrices were drawn for the exposure and each covariate group of the conceptual
11 framework to assess associations between the exposure and the covariates. If both variables
12 were normally distributed, Pearson's r was calculated; otherwise, Spearman's ρ .

1 Associations were assessed using Poisson regression due to the number of people starting
2 KRT being a count variable. Since the outcome variable was KRT incidence (a rate), an offset
3 term was included to allow for the differing population sizes of each CCG (denominator data).
4 It was assumed that the CCGs were independent and could be given equal weight. Non-
5 linearity between exposure/covariates and KRT incidence was assessed using scatter plots
6 and quadratic terms. Only CKD prevalence showed a non-linear relationship with KRT
7 incidence. Therefore, CKD prevalence and the Index of Multiple Deprivation (IMD) score
8 (relative score) were transformed into categorical variables in quintiles. Similarly, a categorical
9 variable was defined for the exposure in addition to the continuous to investigate potential
10 non-linear associations.

11 Following the hierarchical conceptual framework, a sequence of three Poisson models was
12 created. Some variables were strongly correlated, which could have led to multicollinearity
13 after including them in the models. That was assessed by comparing the crude and the fitted
14 models' root-mean-square errors (RMSE).

15 It was tested whether the association between PUCP and KRT incidence was modified by the
16 a-priori-defined effect modifier AKI mortality, using a simplified full model for which AKI
17 mortality was recoded to a binary variable (low/high fraction) based on an equally large
18 population in each fraction. Evidence of effect modification was assessed using LRTs.

19 For all Poisson models, LRTs were conducted to assess the evidence for a difference in rates.

20 Due to the slight change in the boundaries between 3 CCG pairs between 2019 and 2021,
21 these pairs were merged for sensitivity analysis. A second sensitivity analysis was done using
22 the ONS population denominator data.

23 Statistical analysis was performed in R Studio 2023.06.0 (20). Maps were created using QGIS
24 3.22 (21).

1 RESULTS

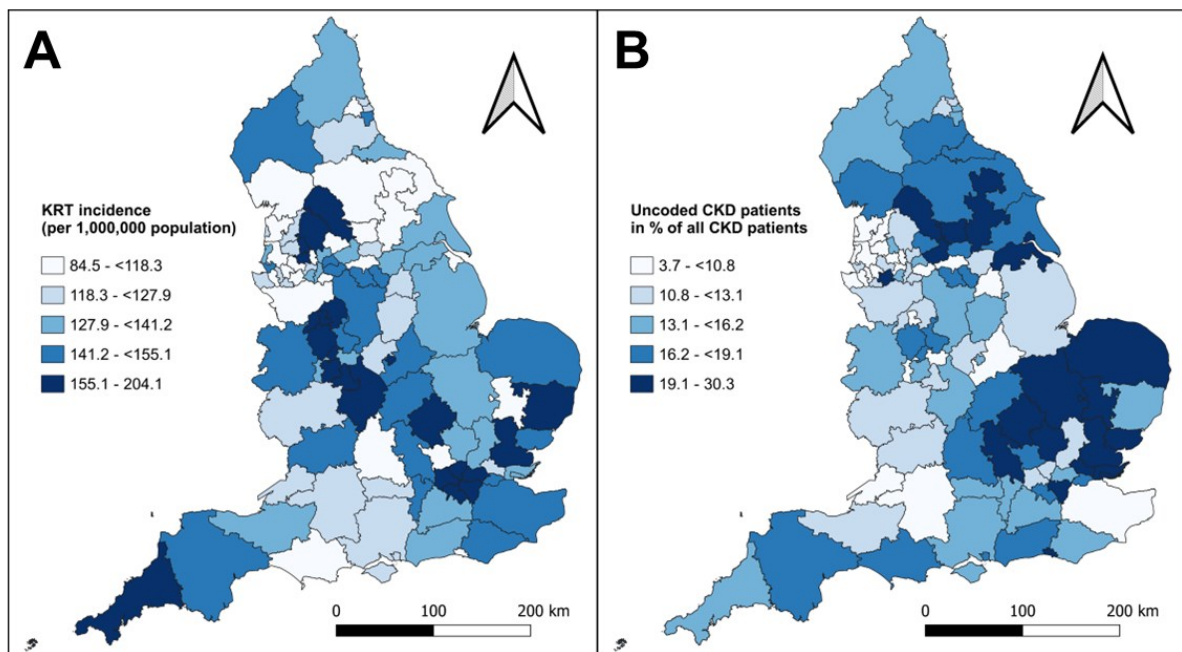
2 Description of KRT incidence and PUCP

3 From 01/2019 to 12/2021, 20,409 adults in England started KRT and the crude overall
4 incidence rate was 141.30/1,000,000, ranging from 84.54/1,000,000 to 204.05/1,000,000 in
5 the different CCGs (Figure 2A). The mean PUCP across all CCGs was 15.47% (SD 5.55),
6 ranging from 3.68% to 30.28% (Figure 2B).

7 CCG characteristics

8 Across KRT quintiles, the median mean-population-age of all CCGs was 49.53 years (IQR
9 47.37-50.79) and lowest in the highest quintile at 47.34 (IQR 45.33-50.25) (Table 1). The
10 median male-population-percentage of all CCGs was 49.55 (IQR 49.11-50.03). There was a
11 trend present for the median percentage of non-white population: in the lowest KRT incidence
12 quintile, the median percentage was only 4.05% (IQR 2.73-10.23) and increased steadily to
13 21.70% (IQR 5.60-31.60) in the fifth quintile. A similar trend was observable for diabetes
14 prevalence with a higher prevalence in CCGs with a higher KRT incidence. These trends could
15 also be observed at the level of the individual CCGs (Supplemental Figure 1).

16 **Figure 2: Spatial distribution of KRT incidence rates (A) and PUCP (B) at CCG level in**
17 **England**



18 Boundary data: Office for National Statistics (22). n=106. CKD Chronic kidney disease; *KRT*
19 *Kidney replacement therapy*; *PUCP* *Percentage of uncoded CKD patients*.

Table 1: CCG characteristics overall and by KRT incidence quintiles

CCG KRT incidence quintile	Overall	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Number of CCGs	106	22	21	21	21	21
CCG KRT incidence per 1,000,000 population	84.5-204.1	84.5-<118.3	118.3-<127.9	127.9-<141.2	141.2-<155.1	155.1-204.1
Outcome						
KRT incidence per 1,000,000 population, mean (SD)	135.39 (22.35)	106.15 (9.18)	123.38 (2.51)	133.92 (4.01)	146.75 (4.09)	168.12 (11.85)
Exposure						
Uncoded CKD patients in % of all CKD patients, mean (SD)	15.47 (5.55)	15.87 (5.59)	11.40 (4.59)	17.42 (6.63)	15.53 (3.80)	15.57 (5.35)
Covariates						
Sociodemographic covariates						
Mean-population-age in years, median (IQR)	49.53 (47.37-50.79)	49.55 (48.67-50.52)	49.20 (47.33-50.35)	49.53 (48.57-51.51)	49.92 (48.78-51.31)	47.34 (45.33-50.25)
Male population in %, median (IQR)	49.55 (49.11-50.03)	49.57 (49.16-49.86)	49.62 (49.20-50.20)	49.29 (48.88-49.97)	49.31 (48.77-49.73)	50.03 (49.53-50.48)
IMD score, median (IQR)	21.35 (17.12-29.48)	20.80 (16.40-27.08)	23.60 (18.30-29.60)	19.40 (15.50-25.20)	20.40 (18.80-27.10)	23.00 (18.20-30.90)
Non-white population in %, median (IQR)	6.35 (3.30-12.12)	4.05 (2.73-10.23)	4.60 (3.00-9.80)	5.90 (3.10-9.70)	6.90 (4.00-9.80)	21.70 (5.60-31.60)
Healthcare quality covariates						
Hypertension treatment goal achieved in %, mean (SD)	60.12 (3.63)	60.65 (3.52)	60.68 (3.25)	59.70 (4.27)	60.05 (4.21)	59.49 (2.87)
Diabetes treatment goal achieved in %, mean (SD)	61.52 (2.32)	61.92 (2.15)	60.92 (2.49)	62.11 (2.80)	61.04 (1.97)	61.59 (2.09)
Mean-KRT-starting-age in years, mean (SD)	61.76 (2.50)	61.67 (2.29)	61.32 (2.71)	61.90 (2.42)	62.66 (2.04)	61.24 (2.92)
Health status covariates						
CKD prevalence in %, mean (SD)	4.77 (1.21)	4.69 (0.98)	4.99 (1.08)	4.60 (1.10)	5.09 (1.28)	4.10 (1.14)
Hypertension prevalence in %, mean (SD)	16.76 (2.32)	16.52 (2.54)	16.74 (2.26)	16.55 (2.23)	17.15 (1.66)	15.70 (2.81)
Diabetes prevalence in %, mean (SD)	7.46 (0.90)	6.99 (0.94)	7.43 (0.80)	7.52 (0.86)	7.55 (0.55)	7.80 (1.12)
AKI stage 2/3 incidence per 1,000 population, median (IQR)	3.51 (3.05-3.88)	3.43 (2.94-3.89)	3.58 (3.35-4.00)	3.71 (3.06-3.81)	3.42 (3.16-3.68)	3.51 (2.65-4.08)
AKI mortality in % of AKI patients, median (IQR)	24.53 (23.15-25.53)	24.17 (22.23-25.34)	24.42 (23.56-25.14)	25.04 (24.11-25.67)	24.51 (23.09-25.81)	24.98 (23.68-25.55)

AKI Acute kidney injury; CCG Clinical commissioning group; CKD Chronic kidney disease; IMD Index of multiple deprivation; IQR Interquartile range; KRT Kidney replacement therapy; SD Standard deviation.

1 **Correlations of the PUCP and covariates**

2 A crude negative correlation was observed between the PUCP and IMD ($\rho=-0.245$) (Figure
3 3A). Between the sociodemographic covariates, strong negative correlations were found with
4 the mean-population-age: a higher mean-population-age was associated with a lower male
5 population ($\rho=-0.677$), a lower IMD score ($\rho=-0.378$) and a lower non-white population ($\rho=-$
6 0.793). Conversely, a higher percentage of male population was positively correlated with a
7 higher IMD score ($\rho=0.478$) and a higher non-white population ($\rho=0.526$).

8 There was no evidence of any crude correlations between the PUCP and one of the healthcare
9 quality covariates (Figure 3B). The healthcare quality covariates showed a positive correlation
10 between the percentage of diabetes patients who had achieved their treatment goal and the
11 mean-KRT-starting-age ($r=0.219$).

12 A higher PUCP was crudely correlated with lower CKD prevalence ($r=-0.246$), hypertension
13 prevalence ($r=-0.391$) and AKI stage 2/3 incidence ($\rho=-0.372$) (Figure 3C). Between the health
14 status covariates, correlations were positive: a higher CKD prevalence was strongly correlated
15 with a higher hypertension prevalence ($r=0.625$) and a higher AKI stage 2/3 incidence
16 ($\rho=0.354$). A higher AKI stage 2/3 incidence was also strongly correlated with a higher
17 hypertension prevalence ($\rho=0.695$), a higher diabetes prevalence ($\rho=0.536$) and a higher AKI
18 mortality ($\rho=0.496$).

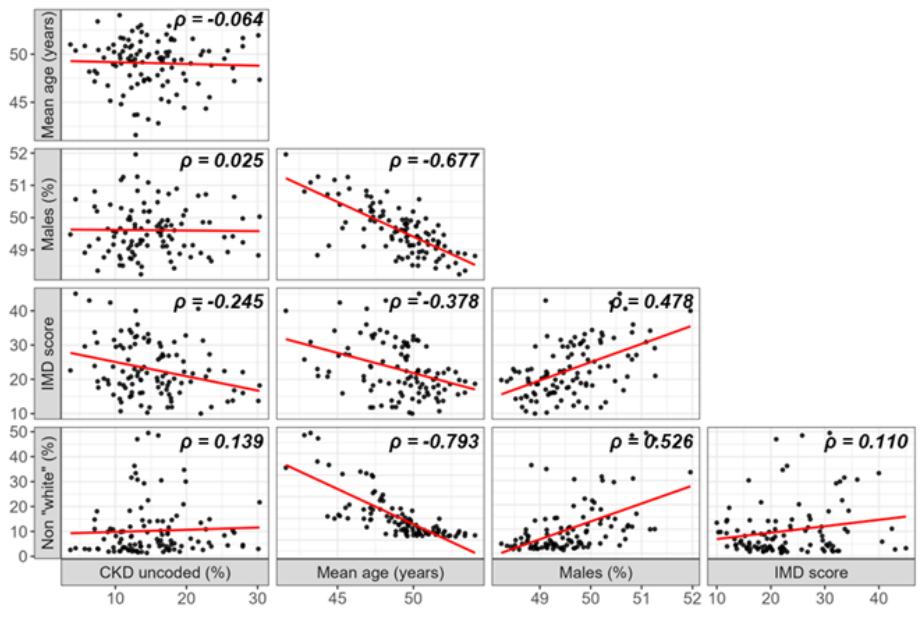
19 The correlation coefficients and corresponding p-values for the correlations of all variables,
20 including KRT incidence, can be found in Supplemental Table 2.

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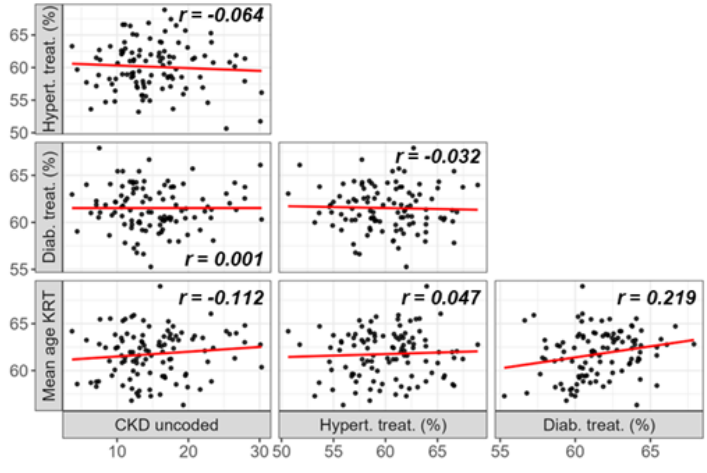
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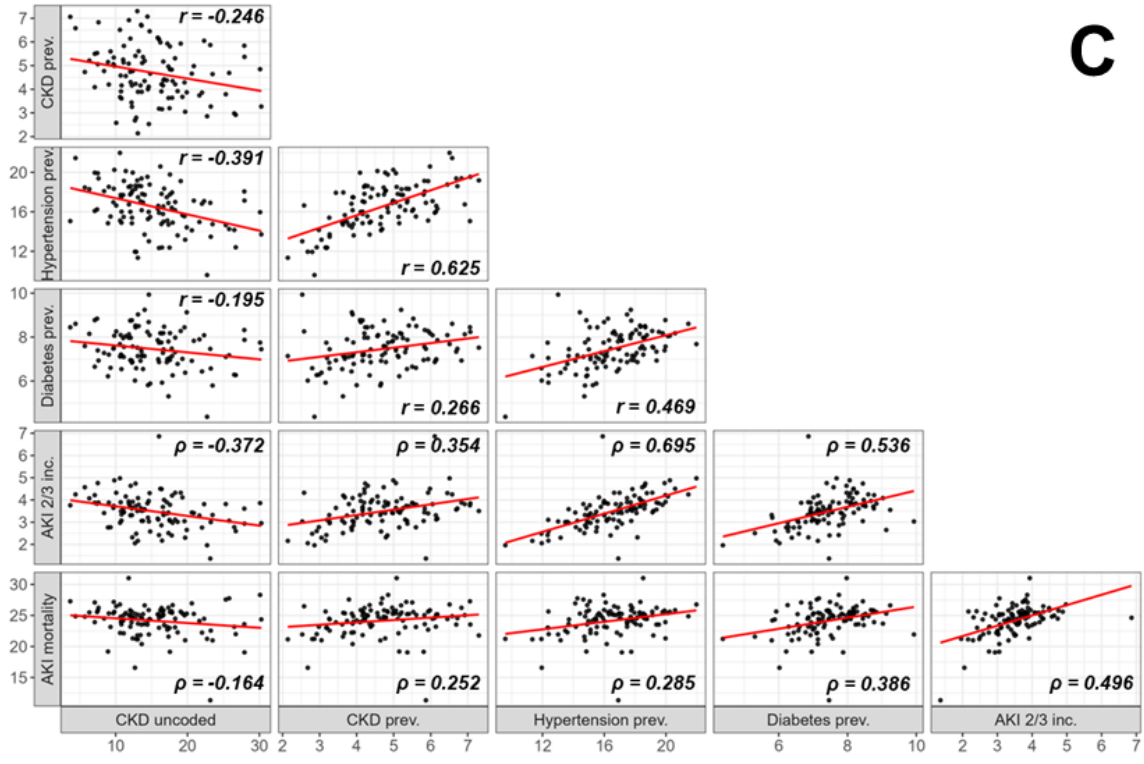
A



B



C



1 **Figure 3: Cross-correlation scatter plots of the PUCP and sociodemographic covariates**
2 **(A), the PUCP and healthcare quality covariates (B), and the PUCP and health status**
3 **covariates (C).** If both variables were normally distributed, the correlation coefficient
4 Pearson's r and otherwise Spearman's ρ are presented for each correlation. $n=106$. *AKI Acute*
5 *kidney injury; CKD Chronic kidney disease; Diab. treat. Diabetes treatment goal achieved;*
6 *Hypert. treat. Hypertension treatment goal achieved; IMD Index of multiple deprivation; inc.*
7 *Incidence; pop. Population; prev. Prevalence; KRT Kidney replacement therapy.*

8

9 **Univariable and multivariable analysis**

10 Univariable Poisson regression, showed no evidence of an association between the crude
11 PUCP (as a continuous variable) and KRT incidence (RR 1.000, 95% CI 0.997-1.003) (Table
12 2). However, when included as a categorical variable, there was very strong evidence
13 ($p<0.001$) for a difference in the crude KRT incidence rates, indicating a non-linear
14 association, with the highest rate in the second quintile (156.89, 95% CI 152.03-161.88).

15 After adjusting for all covariates (Model 3), an association between the PUCP as a continuous
16 variable and KRT incidence was found (RR 1.004, 95% CI 1.000-1.008, $p=0.029$). An
17 association was also present when using the PUCP as a categorical variable ($p=0.030$). The
18 difference in rates between the first and the other quintiles ranged from a 3.5% higher rate in
19 the fourth and an 8% higher rate in the second quintile. The RMSE consistently decreased
20 across all models, indicating that the models benefitted from including the additional
21 covariates.

1 **Table 2: Univariable (crude) and multivariable Poisson regression models of the**
 2 **association between the PUCP and the KRT incidence**

	Rate Ratio (95% CI)	p-value
Crude		
Uncoded CKD patients in % (continuous)	1.000 (0.997-1.003)	0.886
Uncoded CKD patients in % (quintiles)		
Lowest	1	<0.001
2	1.221 (1.167-1.277)	
3	1.123 (1.074-1.174)	
4	1.075 (1.029-1.123)	
Highest	1.099 (1.051-1.149)	
Model 1¹		
Uncoded CKD patients in % (continuous)	1.002 (0.999-1.005)	0.149
Uncoded CKD patients in % (quintiles)		
Lowest	1	0.062
2	1.033 (0.982-1.087)	
3	1.051 (1.003-1.102)	
4	1.000 (0.954-1.048)	
Highest	1.044 (0.996-1.093)	
Model 2²		
Uncoded CKD patients in % (continuous)	1.003 (1.000, 1.006)	0.093
Uncoded CKD patients in % (quintiles)		
Lowest	1	0.360
2	1.020 (0.969, 1.075)	
3	1.030 (0.982, 1.082)	
4	1.000 (0.953, 1.050)	
Highest	1.037 (0.990, 1.087)	
Model 3³		
Uncoded CKD patients in % (continuous)	1.004 (1.000, 1.008)	0.029
Uncoded CKD patients in % (quintiles)		
Lowest	1	0.030
2	1.080 (1.021, 1.143)	
3	1.061 (1.009, 1.116)	
4	1.035 (0.982, 1.090)	
Highest	1.077 (1.020, 1.138)	

3 ¹: Adjusted for sociodemographic covariates

4 ²: Adjusted for sociodemographic and healthcare quality covariates

5 ³: Adjusted for sociodemographic, healthcare quality and health status covariates

6 p-values are calculated using likelihood-ratio tests. n=106. *CI Confidence interval; CKD*
 7 *Chronic kidney disease.*

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1 **Effect modification**

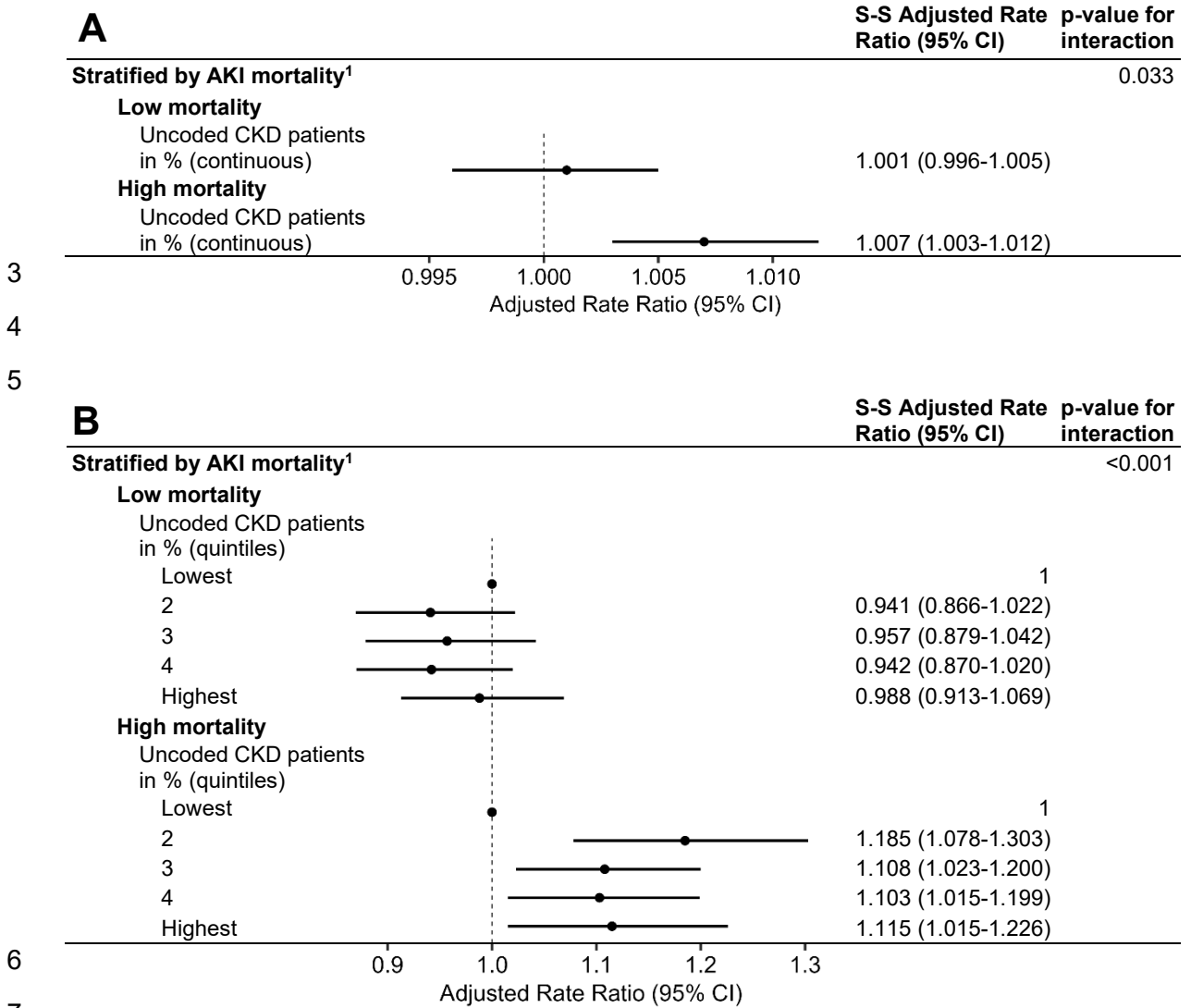
2 Considering the PUCP as a continuous variable, there was some evidence ($p=0.033$) for effect
3 modification: in CCGs with low AKI mortality, there was no evidence of an association with
4 KRT incidence (RR 1.001, 95% CI 0.996-1.005), whereas in CCGs with high AKI mortality, a
5 strong association was found (RR 1.007, 95% CI 1.003-1.012) (Figure 4).

6 Using the PUCP as a categorical variable, there was very strong evidence ($p<0.001$) for effect
7 modification by AKI mortality: In CCGs with low AKI mortality, there was no evidence of an
8 association with KRT incidence. However, in CCGs with high AKI mortality, KRT incidence
9 rates from the second up to the fifth quintile were higher than in the first quintile, with the
10 highest rate in the second quintile, 18% higher than in the first one.

11 Similar results of the effect of AKI mortality on the association between PUCP and KRT
12 incidence were found when using the merged CCG data or population/denominator data from
13 the ONS (Supplemental Table 3 and 4).

14

1 **Figure 4: Stratum-specific adjusted rate ratios for the effect of AKI mortality (low/high)**
 2 **on the association between PUCP and KRT incidence**



8 ¹: Adjusted for sociodemographic, healthcare quality and health status covariates

9 The effect of AKI mortality is assessed using PUCP as a continuous (A) and categorical (B)
 10 variable. p-values are calculated using likelihood-ratio tests. n=106. AKI Acute kidney injury,
 11 CI Confidence interval; CKD Chronic kidney disease; S-S Stratum specific.

12

1 **DISCUSSION**

2 **Summary**

3 In this study PUCP was non-linearly associated with the KRT incidence at CCG level in
4 England, with very strong evidence for an effect modification of this association by AKI
5 mortality in that CCGs with higher AKI mortality were observed to have an association of PUCP
6 with KRT, whilst no such association was observed for CCGs with low AKI mortality.

7 **Comparison with existing literature**

8 The PUCP at CCG level was used in this study as a marker for the care quality for CKD
9 patients. The positive association between successful CKD-specific treatments and a slowed
10 progression of CKD has already been described (23). A lower KRT incidence rate might also
11 be driven by more elderly and multimorbid patients consciously deciding against starting KRT.
12 Given that such a decision is usually made with the treating doctor, it can be considered part
13 of good care.

14 The large regional differences in KRT incidences and the PUCP have already been described
15 in previous work, where other risk factors such as ethnicity and diabetes prevalence were
16 identified (24,25). Differences were further aggravated during the COVID-19 pandemic
17 (18,26,27).

18 The effect modification of the association between the PUCP and KRT incidence by AKI
19 mortality showed that care for CKD patients might be critical in frail populations. It has been
20 shown that over 70% of patients reaching KF are frail (28). Furthermore, higher frailty
21 incidence rates have been observed in patients with a faster decline in kidney function, which
22 might have been additionally accelerated by COVID-19 infections (29). Finally, it has been
23 shown that frailty is an independent risk factor for KF and the need for KRT (30). This might
24 explain why better care in this population is particularly associated with a lower KRT incidence.

25 An explanation of the non-linear associations found might be explained by wide range of
26 percentages the first quintile covered. Therefore, the lower KRT incidence in this quintile could
27 be driven by CCGs with a very low PUCP and presumed excellent care. However, using
28 quintiles is a rough method to assess for more flexible non-linear associations higher than
29 quadratic terms.

30 **Strengths and limitations**

31 An ecological study was chosen because the PUCP is a structural factor, representing
32 practices or areas, and its association with KRT incidence in the population was of interest
33 (31). Using data from only one country reduces the problem of systematic differences which

1 can be observed when using data from different countries. Routinely collected, aggregated
2 data with broad coverage ensures that the entire population is included, reducing selection
3 bias. However, 5% of GP practices did not participate in the CVDPREVENT Audit, which might
4 have led to measurement error of the PUCP (32). However, inferences of causality should not
5 be concluded from ecological studies. They can only create hypotheses that should be tested
6 using individual-level data. This study compared CCGs in England but not at different time
7 points. It was not possible to calculate incidences for the individual years due to the
8 sparseness of the data. Thus, it was not possible to depict the development of KRT incidence
9 over time, nor to show any variability over this period. However, the COVID-19 pandemic had
10 a massive impact on healthcare and KRT incidence, and trends established using data pre-
11 and post-COVID-19 would not have been meaningful (26,27,33).

12 Although the final model adjusted for various covariates, unmeasured confounding due to
13 covariates not included cannot be ruled out. Ideally, frailty should not be defined using proxies
14 but the validated Fried frailty criterion (34), however, these data are not available at population
15 level.

16 Data on ethnicity was only available from the last Census 2011. It is therefore possible that
17 these data do not entirely represent ethnicity in the period 2019-2021.

18 CCGs, on the basis of which the analysis was carried out, have been replaced by ICBs and
19 therefore no longer exist. However, for the analysis it was important to use the groupings
20 corresponding to the data generation process to determine the impact of variation in care at
21 the primary care level on RRT rates. Furthermore, we wanted to preserve the granularity that
22 is crucial for signal detection in ecological studies such as ours, which would have been lost
23 if we had lumped the data further into larger ICBs. Finally, CCGs continue to exist in the form
24 of sub-ICBs, so they can still be seen as an organisational structure, albeit in a different role
25 to the CCGs.

26 **Implications for Research and/or practice**

27 This study shows at an ecological level that there is indirect evidence that conscious
28 awareness of CKD at GP level, in the form of appropriate coding, may be associated with
29 lower KRT incidence rates, particularly in areas with a high proportion of frail people. This can
30 have a significant impact on the ICB budget, which from April 2025 has to cover RRT provision.
31 Especially in the wake of the COVID-19 pandemic, which has disrupted healthcare and
32 affected KRT incidence, PUCP follow-up data may be the first way to estimate future KRT
33 needs, as extrapolating incidences using previous years is no longer possible after the
34 pandemic.

1 However, a single ecological study's results do not justify changes in the current policy. Further
2 research, including individual-level studies, is needed to strengthen the evidence found and
3 guide policymakers on which aspects of care quality are crucial for avoiding KRT.

4

1 **Funding**

2 Not applicable.

3 **Ethical approval**

4 The LSHTM Ethics Committee approved the project (ref: 28430). The aggregated data from
5 the UKRR was requested (application code AD99), the request was approved, and the data
6 was provided. All other data were publicly available.

7 **Data availability**

8 All data can be shared on reasonable request to the corresponding author.

9 **Competing interests**

10 All authors declare that they have no competing interests.

11 **Acknowledgements**

12 We would like to thank the UKRR data management team who compiled the data specifically
13 for this study.

1 LIST OF ABBREVIATIONS

2	AKI	Acute kidney injury
3	CCG	Clinical commissioning group
4	CKD	Chronic kidney disease
5	CVDPREVENT	Cardiovascular Disease Prevention Audit
6	Diab. treat.	Diabetes treatment goal achieved
7	GP	General practitioner
8	GFR	Glomerular filtration rate
9	Hypert. treat.	Hypertension treatment goal achieved
10	IMD	Index of Multiple Deprivation
11	inc.	Incidence
12	IQR	Interquartile range
13	KF	Kidney failure
14	KRT	Kidney replacement therapy
15	LRT	Likelihood ratio test
16	NHS	National Health Service
17	OHID	Office for Health Improvement and Disparities
18	ONS	Office for National Statistics
19	pop.	Population
20	prev.	Prevalence
21	PUCP	Percentage of uncoded chronic kidney disease patients
22	RMSE	Root-mean-square error
23	SD	Standard deviation
24	SE	Standard error
25	SES	Socioeconomic status
26	UK	United Kingdom
27	UKRR	United Kingdom Renal Registry

28

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