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Wong, K., Pitcher, D., Braddon, F. et al. (299 more authors) (2024) Description and cross-sectional analyses of 25,880 adults and children in the UK National Registry of rare kidney diseases cohort. *Kidney International Reports*, 9 (7). pp. 2067-2083. ISSN 2468-0249

<https://doi.org/10.1016/j.ekir.2024.04.062>

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Description and Cross-Sectional Analyses of 25,880 Adults and Children in the UK National Registry of Rare Kidney Diseases Cohort



Katie Wong^{1,2}, David Pitcher^{1,2}, Fiona Braddon¹, Lewis Downward¹, Retha Steenkamp³, Sherry Masoud^{1,2}, Nicholas Annear⁴, Jonathan Barratt⁵, Coralie Bingham⁶, Richard J. Coward⁷, Tina Chrysochou⁸, David Game⁹, Sian Griffin¹⁰, Matt Hall¹¹, Sally Johnson¹², Durga Kanigicherla⁸, Fiona Karet Frankl¹³, David Kavanagh^{14,15}, Larissa Kerecuk¹⁶, Eamonn R. Maher¹³, Shabbir Moochhala¹⁷, Jenny Pinney¹⁸, John A. Sayer¹⁹, Roslyn Simms²⁰, Smeeta Sinha^{8,21}, Shalabh Srivastava²², Frederick W.K. Tam²³, Kay Thomas⁹, A. Neil Turner²⁴, Stephen B. Walsh², Aoife Waters²⁵, Patricia Wilson², Edwin Wong¹⁴, Karla Therese L. Sy²⁶, Kui Huang²⁶, Jamie Ye²⁶, Dorothea Nitsch^{3,27}, Moin Saleem⁷, Detlef Bockenhauer^{2,25}, Kate Bramham^{1,28}, Daniel P. Gale^{1,2}, and RaDaR consortium²⁹

¹National Registry of Rare Kidney Diseases, Bristol, UK; ²Department of Renal Medicine, University College London, UK; ³UK Renal Registry, Bristol, UK; ⁴St George's, University of London, UK; ⁵University of Leicester, UK; ⁶University of Exeter, UK; ⁷University of Bristol, UK; ⁸University of Manchester, UK; ⁹Guy's and St Thomas' NHS Foundation Trust, UK; ¹⁰Cardiff University, UK; ¹¹University of Nottingham, UK; ¹²Great North Children's Hospital, Newcastle Upon Tyne, UK; ¹³University of Cambridge, UK; ¹⁴National Renal Complement Therapeutics Centre (NRCTC), Newcastle upon Tyne Hospitals NHS Foundation Trust, UK; ¹⁵Complement Therapeutics Research Group, Translational and Clinical Research Institute, Newcastle University, UK; ¹⁶Birmingham Women's and Children's NHS Foundation Trust, UK; ¹⁷Royal Free London NHS Foundation Trust, UK; ¹⁸University Hospitals Birmingham NHS Foundation Trust, UK; ¹⁹Translational and Clinical Research Institute, Newcastle University, UK; ²⁰Department of Infection, Academic Unit of Nephrology, Immunity and Cardiovascular Disease, University of Sheffield, UK; ²¹Northern Care Alliance NHS Foundation Trust, UK; ²²South Tyneside and Sunderland NHS Foundation Trust, UK; ²³Department of Immunology and Inflammation Centre for Inflammatory Disease, Imperial College London, UK; ²⁴Edinburgh University, UK; ²⁵Great Ormond Street Hospital for Children NHS Foundation Trust, London, UK; ²⁶Pfizer, Inc, New York, USA; ²⁷London School of Hygiene and Tropical Medicine, London, UK; and ²⁸King's College London and King's Health Partners, London, UK

Introduction: The National Registry of Rare Kidney Diseases (RaDaR) collects data from people living with rare kidney diseases across the UK, and is the world's largest, rare kidney disease registry. We present the clinical demographics and renal function of 25,880 prevalent patients and sought evidence of bias in recruitment to RaDaR.

Methods: RaDaR is linked with the UK Renal Registry (UKRR, with which all UK patients receiving kidney replacement therapy [KRT] are registered). We assessed ethnicity and socioeconomic status in the following: (i) prevalent RaDaR patients receiving KRT compared with patients with eligible rare disease diagnoses receiving KRT in the UKRR, (ii) patients recruited to RaDaR compared with all eligible unrecruited patients at 2 renal centers, and (iii) the age-stratified ethnicity distribution of RaDaR patients with autosomal dominant polycystic kidney disease (ADPKD) was compared to that of the English census.

Results: We found evidence of disparities in ethnicity and social deprivation in recruitment to RaDaR; however, these were not consistent across comparisons. Compared with either adults recruited to RaDaR or the English population, children recruited to RaDaR were more likely to be of Asian ethnicity (17.3% vs. 7.5%, P -value < 0.0001) and live in more socially deprived areas (30.3% vs. 17.3% in the most deprived Index of Multiple Deprivation (IMD) quintile, P -value < 0.0001).

Conclusion: We observed no evidence of systematic biases in recruitment of patients into RaDaR; however, the data provide empirical evidence of negative economic and social consequences (across all ethnicities) experienced by families with children affected by rare kidney diseases.

Correspondence: Daniel P. Gale, UCL Department of Renal Medicine, Royal Free Hospital, Rowland Hill Street, London, NW3 2PF, UK. E-mail: d.gale@ucl.ac.uk

²⁹Members of RaDaR Consortium are listed in the [Appendix](#).

Received 27 March 2024; accepted 24 April 2024; published online 9 May 2024

Kidney Int Rep (2024) 9, 2067–2083; <https://doi.org/10.1016/j.ekir.2024.04.062>

KEYWORDS: ethnicity; RaDaR; rare kidney disease registry; rare kidney diseases; social deprivation

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A rare disease is defined in Europe as a condition affecting less than 1 in 2000 people,¹ and in the USA as affecting fewer than 200,000 individuals in the country.² Rare kidney diseases make a significant contribution to the burden of kidney disease in the UK and globally. At least 25% of adults and over 50% of children receiving KRT have a rare disease³ with “glomerulonephritis” being the single commonest category of primary renal disease among UK patients receiving KRT.⁴

Small patient numbers can result in challenges in clinical management and research in rare diseases. Lack of clinical experience, even in large academic centers can lead to delays or errors in diagnosis and treatment of rare diseases; and low disease incidence alongside underdiagnosis can make identification of patients eligible for clinical trials and observational studies challenging. Adequate patient numbers for meaningful analysis may only be achieved through collaboration between multiple large renal centers, associated with considerable administrative burden.⁵

Kidney disorders can cause multisystem dysfunction and may require complex multidisciplinary care at different specialist centers. Advances in KRT have led to people with rare kidney disorders surviving for decades with kidney failure (KF),¹ so the requirement for long-term follow-up data is paramount. For children with rare kidney diseases, life-time follow-up across different specialist pediatric and adult health care centers across different regions may be needed, leading to fragmentation of records across multiple databases, systems, and health care providers, which is challenging to access for research. Rare kidney disorders are therefore frequently poorly characterized, lacking published data on the prevalence rates, determinants, distribution, and long-term outcomes of these diseases.

RaDaR, set-up in 2010 by the UK Kidney Association with funding from the Medical Research Council, Kidney Care UK, and Kidney Research UK, was designed to address these challenges by collecting longitudinal data (without biological specimens) for UK adults and children with rare kidney diseases. Uniquely embedded with the publicly funded National Health Service (NHS) to which all UK residents have free access, RaDaR is hosted by the UKRR and has UK-wide ethical approval as a research registry, enabling automated collection of retrospective and prospective

data for patients across multiple regions. The aims of RaDaR include the following: (i) to better understand the natural history of rare kidney diseases (as we recently reported⁶), (ii) to assess long-term effects of therapies, (iii) to identify cohorts eligible for clinical research, and (iv) provide infrastructure for individual rare disease studies and subregistries.

To our knowledge, RaDaR is the largest rare kidney disease registry worldwide. Here we describe the set-up and data flow into RaDaR, and present cross-sectional analyses of 25,880 prevalent patients and minimum point prevalence estimates for 21 rare kidney diseases in the UK.

METHODS

Structure of RaDaR

Recruitment and data transfer are summarized in [Figure 1](#). All participants sign a consent form agreeing to storage and analysis of their clinical data; in most cases, to linking their data to that held in other databases, studies, and registries; and to be contacted for future research studies they may be eligible for. All data are held centrally in a Structured Query Language database at the UKRR. National Institute for Health and Care Research infrastructure and research nurse supports NHS sites to manually enter a minimal set of mandatory fields at the time of recruitment to RaDaR; this infrastructure has also supported other national research programs such as the RECOVERY⁷ trial. Manual data entry is automatically checked using defined ranges to identify implausible data.

Data on all patients recruited to RaDaR were extracted on July 25, 2022.

Rare Disease Groups (RDGs)

Participants are recruited into 29 RDGs, which may comprise a single disease or groups of renal diagnoses. Full eligibility criteria for each RDG are shown in [Supplementary Table S15](#) and available online at https://ukkidney.org/sites/renal.org/files/radar/Inclusion-Exclusion_april_2021_v22.pdf.

Data for the following RDGs with >85 patients are presented: ADPKD, autosomal dominant tubulointerstitial kidney disease, atypical hemolytic uremic syndrome, Alport syndrome, autosomal recessive polycystic kidney disease and nephronophthisis, HNF1B mutations, IgA nephropathy, idiopathic nephrotic syndrome, membranous nephropathy, monoclonal gammopathy of

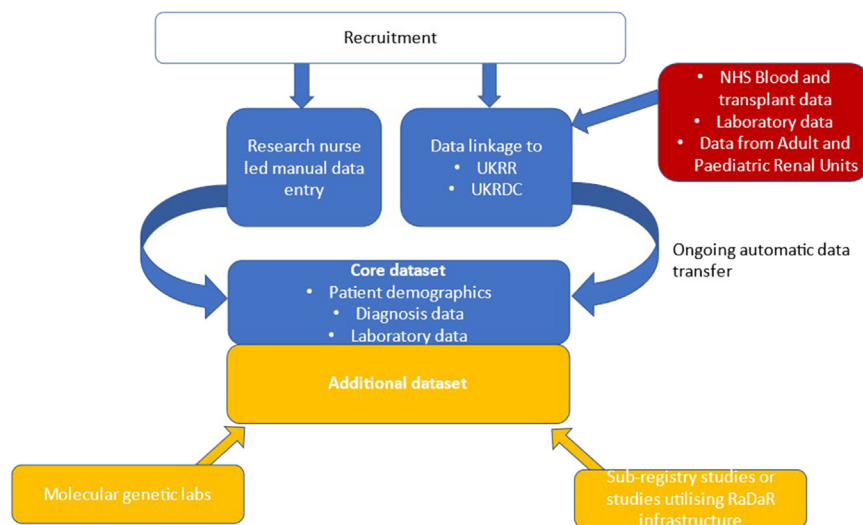


Figure 1. Recruitment and data flow to RaDaR. RaDaR, National Registry of Rare Kidney Diseases; UKRDC, UK Renal Data Collaboration; UKRR, UK Renal Registry.

renal significance, membranoproliferative glomerulonephritis and C3 glomerulopathy; pregnancy, inherited renal cancers; retroperitoneal fibrosis, Shiga toxin/verotoxin-producing *Escherichia coli*-associated hemolytic uremic syndrome, tuberous sclerosis complex, vasculitis, cystinosis, cystinuria, primary hyperoxaluria, and tubulopathies. Results for males and females with X-linked Alport syndrome, and individuals with thin basement membrane nephropathy are presented separately because these conditions are usually X-linked or autosomal respectively. Patients with autosomal recessive Alport syndrome have been excluded due to small sample size. Results for the vasculitis RDG are presented stratified into antineutrophil cytoplasmic antibody-associated vasculitis, antiglomerular basement membrane disease, and other vasculitis (including large vessel and IgA vasculitis). The idiopathic nephrotic syndrome cohort is presented stratified into patients with a diagnosis of either steroid sensitive nephrotic syndrome or minimal change disease (SSNS/MCD); steroid resistant nephrotic syndrome, congenital nephrotic syndrome, or focal segmental glomerulosclerosis (SRNS/FSGS); or idiopathic nephrotic syndrome-unspecified (patients without a confirmed diagnosis of SSNS/MCD or SRNS/FSGS).

Data Linkage

RaDaR is linked with the UKRR for data on KRT initiation and death, which receives data from NHS Blood and Transplant for transplantation events. Rates of KRT data received from the UKRR are correct as of 1st January 2022. Routine laboratory data are extracted via automated feed either directly from renal unit information technology systems or via the UK Renal Data Collaboration.

Demographic Data

Self-reported ethnicity (Office of National Statistics census categories⁸) is entered manually by a research nurse at the time of recruitment or populated from existing clinical data provided by the UK Renal Data Collaboration. Sex is reported according to UK Renal Data Collaboration record. Postcodes (zip codes) were used to derive IMD scores as an area level measure of socioeconomic status. IMD is a measure of relative deprivation for small areas within a country from most deprived to least deprived (1 = most deprived). Each country in the UK (England,⁹ Wales,¹⁰ Scotland¹¹ and Northern Ireland¹²) has an IMD. These can then be categorized into country-specific quintiles within each country (quintile 1 = most deprived, quintile 5 = least deprived).

Renal Function

For patients not receiving KRT, estimated glomerular filtration rate was calculated using chronic kidney disease (CKD)-epidemiology collaboration creatinine equation without race adjustment (2009)¹³ or Schwartz equation for patients aged ≤ 16 years.

Missing Data

Available data were presented for each variable and patterns for missing data explored and proportions presented in [Supplementary Tables S1 to S3](#).

Small Number Suppression

Where a risk of reidentification of participants were identified, groups with small numbers were aggregated into larger groups and tabulated data were structured not to report fewer than 6 participants per cell where possible. Where cells contained ≤ 6 counts, this cell was suppressed. To avoid possibility of calculation of

suppressed counts, corresponding cells were rounded to the nearest 5, in accordance with NHS Digital guidance.¹⁴

Minimum Point Prevalence Estimates

UK wide RaDaR point prevalence estimates were calculated using patient numbers for each RDG, and stratified by sex, using Office of National Statistics UK population data¹⁵ and were presented per 100,000 population. Prevalence estimates were also calculated for each RDG for each UK Health Board, and maximum estimated rate for each RDG were presented. Due to the nature of recruitment to RaDaR, which requires informed consent from participants, these estimated UK-wide rates could underestimate the true rate of rare kidney diseases but could be interpreted as minimum possible rates.

Statistical Analyses

Baseline characteristics were presented as frequencies (%) for categorical data and medians (interquartile range) for continuous data. Chi-square or Fisher exact tests were used to compare categorical variables. Statistical analyses were performed using STATA Release 17 (StataCorp LLC, College Station, TX) and SAS version 9.4 (SAS Institute Inc., Cary, NC).

Ethnicity and Social Deprivation Comparisons

For each RDG, the proportion of patients in each ethnic group and each IMD quintile was compared to the overall RaDaR proportion, excluding that RDG. Because ethnic and IMD quintile distributions differed between adult and pediatric populations, these analyses were performed stratified by age category.

Recruitment Comparisons

Primary renal diagnosis is recorded in the UKRR using European Renal Association-European Dialysis and Transplant Association codes¹⁶ and in UK renal center information systems either using primary renal diagnosis codes or free-text. Primary renal diagnosis codes and a list of search terms specific to each RDG were decided with agreement from RDG leads (clinicians with expertise in that rare kidney disease), to generate an overall list of primary renal diagnosis codes and keywords for RaDaR diagnoses ([Supplementary Table S4](#)).

To assess whether some RDGs had recruited a greater proportion of the total eligible patients in the UK than others, living patients in the UKRR receiving KRT who were eligible for RaDaR based on EDTA codes were stratified into their potential RDGs, and the percentage in each RDG compared to the percentage of living patients in RaDaR receiving KRT.

To assess whether there has been ethnic or socioeconomic status recruitment bias, 3 methods were used as follows: (i) ethnicity and socioeconomic status of all prevalent RaDaR patients who had reached KF were compared with patients with a rare kidney diagnosis in the UKRR, (ii) patients recruited to RaDaR from 2 large UK renal centers were compared with all unrecruited patients with a RaDaR eligible diagnosis at those centers, (iii) the age-stratified ethnicity distribution of England according to the 2011 UK census was compared with the ethnicity of prevalent English RaDaR patients with ADPKD. Patients from Scotland, Wales, and Northern Ireland were excluded from comparisons with the 2011 UK census due to lack of available data regarding age-stratified ethnicity from the Office of National Statistics for those nations. English nationality was determined by a home address with an English postcode. More detailed information about these comparisons is presented in the [Supplementary Methods](#).

The RaDaR database has approval for research studies from the NHS South-West-Central Bristol Research Ethics Committee (19/SW/0173). This report was written with reference to the Strengthening the Reporting of Observation Studies in Epidemiology (STROBE) statement.¹⁷ Additional methods can be found in the [Supplementary Methods](#).^{S1, S2}

RESULTS

As of July 2022, RaDaR recruited patients from 108 NHS sites (96 adult and 12 pediatric) across England ($n = 91$), Scotland ($n = 9$), Wales ($n = 3$), and Northern Ireland ($n = 5$). Most patients have been recruited from English renal units ($n = 23,776$, 92%). Recruitment at each center is shown in [Supplementary Table S14](#). Data from RDGs with ≥ 85 patients recruited are presented.

Clinical demographics of the RaDaR Patient Population

Clinical characteristics of 25,880 prevalent patients in RaDaR on July 25, 2022, are presented in [Table 1](#); 2957 patients (11%) are now deceased. One hundred twenty-five patients (0.5%) have more than 1 diagnosis recorded; the majority of these are in the pregnancy RDG (115/125, 92%). A total of 5260 renal pathology reports are available for 4184 participants, mostly in the larger glomerular disease RDGs.

The largest RDGs by patient number are ADPKD ($n = 7112$), vasculitis ($n = 3997$), idiopathic nephrotic syndrome ($n = 3917$), and IgA nephropathy ($n = 3796$). Conditions not presented due to low numbers are as follows: adenine phosphoribosyltransferase deficiency ($n = 9$), BK nephropathy ($n = 62$), CKD due to genetic factors in people of African Ancestry (CKD-AFRICA)

Table 1. Patient demographics of individuals recruited to RaDaR, stratified by rare disease group and current age^a

Rare disease group	Pediatric		Adults		Median current age				Deceased All		
	Pediatric n (%)	Adults n (%)	males	females	males	females	pediatric			adult	
			n (%)	n (%)	n (%)	n (%)	median	(IQR)		median	(IQR)
All RaDaR	1934 (7.5)	23946 (92.5)	1072 (55.4)	862 (44.6)	12811 (53.5)	11135 (46.5)	12	(9.3–15.0)	56	(41.5–67.9)	2956
Monogenic or congenital conditions											
ADPKD	119 (1.7)	6993 (98.3)	59 (49.6)	60 (50.4)	3302 (47.2)	3691 (52.8)	13	(11.2–15.4)	55	(44.1–65.0)	685
ADTKD	≤6 (NR ^b)	190 (>97.0)	0 (0.0)	3 (100.0)	80 (42.6)	108 (57.4)	17	(15.7–17.2)	54	(43.3–63.9)	24
X-linked Alport- female	46 (15.5)	250 (84.5)		46 (100.0)		250 (100.0)	11	(8.7–14.6)	46	(33.3–59.3)	13
X-linked Alport- male	53 (13.8)	332 (86.2)	53 (100.0)		332 (100.0)		12	(10.0–14.9)	43	(29.4–56.4)	27
TBMN	16 (9.9)	146 (90.1)	≤6 (NR)	10 (>63.0)	48 (32.9)	98 (67.1)	12	(9.5–16.1)	47	(32.0–58.6)	3
ARPKD/NPHP	71 (33.0)	144 (67.0)	40 (56.3)	31 (43.7)	64 (44.4)	80 (55.6)	12	(9.2–14.5)	39	(26.5–54.8)	18
Cystinosis	54 (37.5)	90 (62.5)	26 (48.1)	28 (51.9)	43 (47.8)	47 (52.2)	13	(8.9–15.7)	29	(23.6–36.4)	9
Cystinuria	28 (6.1)	432 (93.9)	19 (67.9)	9 (32.1)	222 (51.4)	210 (48.6)	11	(7.2–14.5)	49	(34.4–62.1)	13
Hyperoxaluria	25 (21.7)	90 (78.3)	12 (48.0)	13 (52.0)	59 (65.6)	31 (34.4)	11	(9.0–13.3)	36	(26.4–52.1)	9
HNFB mutations	31 (36.5)	54 (63.5)	19 (61.3)	12 (38.7)	28 (51.9)	26 (48.1)	9	(6.8–14.2)	39	(23.7–51.1)	1
Renal cancer inherited	10 (8.8)	103 (91.2)	≤6 (NR)	≤6 (NR)	39 (37.9)	64 (62.1)	10	(8.4–12.5)	54	(35.4–60.8)	1
Tubulopathies	76 (18.7)	331 (81.3)	54 (71.1)	22 (28.9)	155 (46.8)	176 (53.2)	12	(8.1–15.9)	40	(29.5–56.0)	12
Tuberous sclerosis complex	43 (17.8)	199 (82.2)	16 (37.2)	27 (62.8)	81 (40.7)	118 (59.3)	11	(8.9–15.0)	39	(29.1–51.8)	7
Mostly nonmonogenic or acquired conditions											
aHUS	89 (32.2)	187 (67.8)	43 (48.3)	46 (51.7)	85 (45.5)	102 (54.5)	10	(7.0–13.9)	42	(32.7–56.4)	17
SSNS/MCD	525 (31.8)	1127 (68.2)	329 (62.7)	196 (37.3)	638 (56.6)	489 (43.4)	12	(9.3–14.2)	47	(31.5–63.6)	53
SRNS/FSGS	256 (18.2)	1154 (81.8)	137 (53.5)	119 (46.5)	650 (56.3)	504 (43.7)	13	(9.5–15.5)	49	(30.3–63.8)	126
INS-unspecified	63 (7.4)	792 (92.6)	38 (60.3)	25 (39.7)	449 (56.7)	343 (43.3)	12	(7.7–14.1)	55	(40.9–67.6)	120
IgA nephropathy	40 (1.1)	3756 (98.9)	25 (62.5)	15 (37.5)	2610 (69.5)	1146 (30.5)	14	(12.1–16.4)	53	(42.2–63.5)	351
Membranous nephropathy	≤6 (NR)	2050 (>99.0)	≤6 (NR)	≤6 (NR)	1358 (66.2)	692 (33.8)	14	(13.3–15.1)	66	(55.5–74.6)	384
MGRS	0 (0.0)	144 (100.0)	0 (0.0)	0 (0.0)	74 (51.4)	70 (48.6)			67	(56.1–76.3)	37
MPGN/C3GN	63 (6.8)	869 (93.2)	32 (50.8)	31 (49.2)	454 (52.2)	415 (47.8)	15	(12.5–16.6)	54	(35.3–66.1)	157
Pregnancy	≤6 (NR)	680 (>99.0)		1 (100.0)		681 (100.0)	16	(16.1–16.1)	37	(33.1–42.0)	10
Retroperitoneal fibrosis	0 (0.0)	111 (100.0)	0 (0.0)		72 (64.9)	39 (35.1)			67	(58.5–74.2)	31
STEC HUS	110 (65.9)	57 (34.1)	57 (51.8)	53 (48.2)	24 (42.1)	33 (57.9)	12	(8.7–14.6)	23	(20.1–33.2)	3
ANCA-associated vasculitis	7 (0.4)	1917 (99.6)	0 (0.0)	7 (100.0)	1005 (52.4)	912 (47.6)	14	(13.0–16.4)	70	(58.6–77.0)	451
Anti-GBM disease	≤6 (NR)	115 (>99.0)	0 (0.0)	1 (100.0)	57 (49.6)	58 (50.4)	15	(14.8–14.8)	62	(47.6–71.4)	21
Other vasculitides	200 (10.2)	1757 (89.8)	100 (50.0)	100 (50.0)	886 (50.4)	871 (49.6)	12	(9.7–15.0)	66	(51.0–75.4)	374

ADPKD, autosomal dominant polycystic kidney disease; ADTKD, autosomal dominant tubulointerstitial kidney disease; aHUS, atypical hemolytic uremic syndrome; ANCA, antineutrophil cytoplasmic antibody; ARPKD/NPHP, autosomal recessive polycystic kidney disease and nephronophthisis; C3GN, C3 glomerulopathy; FSGS, focal segmental glomerulosclerosis; GBM, glomerular basement membrane; INS, idiopathic nephrotic syndrome; IQR, interquartile range; MCD, minimal change disease; MGRS, monoclonal gammopathy of renal significance; MPGN, membranoproliferative glomerulonephritis; NR, not reported; RaDaR, National Registry of Rare Kidney Diseases; SRNS, steroid resistant nephrotic syndrome; SSNS, steroid sensitive nephrotic syndrome; STEC HUS, Shiga toxin/verotoxin-producing Escherichia coli-associated hemolytic uremic syndrome; TBMN, thin basement membrane nephropathy.

^aPrevalent patients on July 25, 2022; cells with fewer than 6 patients not reported due to risk of reidentification. Where a cell is not reported due to small numbers, corresponding cell values are rounded to the nearest 5. Individuals with 2 diagnoses are presented once for all RaDaR results, but subsequently included for each diagnosis. Row percentages are presented.

($n = 65$), calciphylaxis ($n = 59$), Fabry disease ($n = 47$), fibromuscular dysplasia ($n = 42$), mitochondrial renal disease ($n = 4$), and pure red cell aplasia ($n = 7$).

Distribution of rare kidney diseases differed between patients currently aged ≤ 18 years (pediatric) and those aged > 18 years old. Predominant rare kidney diseases in adults were ADPKD ($n = 6993$, 29%), vasculitis (16%; antineutrophil cytoplasmic antibody-associated vasculitis, $n = 1917$; antiglomerular basement membrane disease, $n = 115$; and other vasculitides, $n = 1757$), and IgA nephropathy ($n = 3756$, 16%). In children the largest RDGs were idiopathic nephrotic syndrome (44%; SSNS/MCD, $n = 525$; SRNS/FSGS, $n = 256$; and idiopathic nephrotic syndrome-unspecified, $n = 63$), vasculitis (11%; antineutrophil cytoplasmic antibody-associated vasculitis, $n = 7$; antiglomerular basement membrane disease, ≤ 6 ; and other vasculitides, $n = 200$), and Alport syndrome (6%; X-linked males, $n = 53$; X-linked females, $n = 46$; and autosomal dominant tubulointerstitial kidney disease, $n = 16$). The most frequent rare kidney diseases at the time of diagnosis in adults and children were the same.

Males were overrepresented among pediatric patients with cystinuria (68%), HNF1B mutations (61%), idiopathic nephrotic syndrome (60%), and tubulopathies (71%) (due to male-predominant Lowe syndrome); among adult patients with membranous nephropathy (66%), retroperitoneal fibrosis (65%), and primary hyperoxaluria (66%); and among both children and adults with IgA nephropathy (children 63%, adults 70%). Minimum UK point prevalence and maximum area density estimates per 100,000 population for each RDG are presented in [Table 2](#).

Distribution of self-reported ethnicity and socioeconomic status for all RaDaR patients, stratified by RDG are presented in [Figure 2](#). Excluding patients with missing data, 87% of RaDaR participants were White, 1% Mixed, 8% Asian, 3% Black and 1% Other ethnicities. The SSNS/MCD, SRNS/FSGS, IgA nephropathy, tubulopathies, cystinosis and primary hyperoxaluria RDGs, all had a significantly larger proportion of patients from Asian ethnic backgrounds than the total RaDaR population. This was particularly marked in the cystinosis and primary hyperoxaluria RDGs, where the proportions of patients from Asian backgrounds was 24% and 34%, respectively. Similar differences were observed when stratified by pediatric and adult populations ([Supplementary Figures S1 and S2](#)). Individuals recruited to the pregnancy RDG were also more likely to be from Asian (16%) or Black (11%) backgrounds. Children recruited to RaDaR from all 4 UK nations were more likely to be from Asian ethnic backgrounds when compared to adults

recruited to RaDaR (17% vs. 8%, $P < 0.0001$, [Supplementary Table 5](#)). Similarly, Asian ethnic background was overrepresented among English children recruited to RaDaR when compared with children in the general English population (18% vs. 10%, P -value < 0.0001 , [Supplementary Table S6](#)).

Of the patients recruited to RaDaR, 38% had monogenic disorders (disorders usually caused by the presence of 1 or 2 pathogenic variants in a single gene). Stratified by ethnicity, most monogenic disorders were diagnosed in White patients (90.3%) ([Supplementary Table S7](#)). Adults recruited to RaDaR were more likely to be diagnosed with monogenic disorders than children (39% vs. 30%, P -value < 0.0001 , [Supplementary Table S8](#)). Only adults from White, Mixed, and Black backgrounds were more likely to be diagnosed with monogenic disorders compared to children; children from Asian or Other ethnic backgrounds were as likely to have a diagnosis of a monogenic disorder as adults (24% vs. 23%, P -value: 0.7 and 33% vs. 32%, P -value: 0.9, respectively).

Socioeconomic deprivation varied by RDG; patients diagnosed with cystinosis, primary hyperoxaluria, SSNS/MCD, SRNS/FSGS and pregnancy were more likely to be in the most deprived IMD quintile compared to the overall RaDaR population (11% pts, 14% pts, 8% pts, 5% pts, and 9% pts higher, respectively). There were similar differences in both adult and pediatric patients ([Supplementary Figures S3 and S4](#)). Individuals with nonmonogenic disorders were more likely to be in the most deprived IMD quintile compared to those with monogenic disorders (19.2% vs. 16.9%, P -value < 0.0001); however, this association was attenuated when stratified by ethnicity ([Supplementary Table S9](#)). Individuals with autosomal dominant conditions were less likely to be in the most deprived quintile compared to those with autosomal recessive, X-linked or nonmonogenic disorders (16% vs. 20% vs. 19%, respectively; P -value < 0.0001 ; [Supplementary Table S10](#)).

More pediatric patients were in the most deprived IMD quintile compared to adults recruited to RaDaR (30% vs. 17%, [Supplementary Table S5](#)), and compared to children in the general English population ([Supplementary Table S6](#)). Pediatric patients of White, Asian, and other ethnicities were all more likely to be in the most deprived IMD quintile compared to adults (25% vs. 16%, $P < 0.0001$; 54% vs. 31%, $P < 0.0001$; 50% vs. 25%, $P = 0.02$, respectively; [Supplementary Table S11](#)). Children (with nonmonogenic [30.2% vs. 18.2%, P -value < 0.0001] and monogenic [30.5% vs. 16.1%, P -value < 0.0001] disorders across all modes of inheritance) were more likely to be in the most deprived quintile

Table 2. RaDaR point prevalence rates and maximum area density estimates per 100,000 population,^a stratified by rare disease group and sex

Rare disease group	RaDaR point prevalence estimates	RaDaR maximum area density estimates	RaDaR point prevalence estimates	
			males	females
All RDGs	35.90 (35.46–36.34)	65.24 (58.65–72.56)	38.56 (37.92–39.21)	33.24 (32.65–33.84)
ADPKD	9.87 (9.64–10.10)	22.74 (19.22–26.91)	9.34 (9.03–9.66)	10.40 (10.07–10.73)
ADTKD	0.26 (0.23–0.30)	1.05 (0.74–1.47)	0.22 (0.18–0.28)	0.31 (0.26–0.37)
X-linked Alport- female	0.41 (0.37–0.46)	3.75 (0.53–26.65)		0.82 (0.73–0.92)
X-linked Alport- male	0.53 (0.48–0.59)	2.59 (0.83–8.02)	1.07 (0.97–1.18)	
TBMN	0.22 (0.19–0.26)	1.61 (1.04–2.50)	0.15 (0.11–0.20)	0.30 (0.25–0.36)
ARPKD/NPHP	0.30 (0.26–0.34)	0.93 (0.30–2.87)	0.29 (0.24–0.35)	0.31 (0.26–0.37)
Cystinosis	0.20 (0.17–0.23)	3.75 (0.53–26.65)	0.19 (0.15–0.24)	0.21 (0.17–0.26)
Cystinuria	0.64 (0.58–0.70)	2.17 (1.26–3.74)	0.67 (0.59–0.76)	0.61 (0.53–0.69)
Hyperoxaluria	0.16 (0.13–0.19)	0.96 (0.58–1.59)	0.20 (0.16–0.25)	0.12 (0.09–0.16)
HNFB mutations	0.12 (0.10–0.15)	1.02 (0.59–1.76)	0.13 (0.10–0.17)	0.11 (0.08–0.14)
Renal cancer inherited	0.16 (0.13–0.19)	2.27 (1.51–3.41)	0.12 (0.09–0.17)	0.19 (0.15–0.24)
Tubulopathies	0.56 (0.51–0.62)	4.36 (0.61–30.95)	0.58 (0.51–0.66)	0.55 (0.48–0.63)
Tuberous sclerosis complex	0.34 (0.30–0.38)	0.87 (0.52–1.44)	0.27 (0.22–0.33)	0.40 (0.34–0.47)
aHUS	0.38 (0.34–0.43)	1.34 (0.34–5.37)	0.35 (0.30–0.42)	0.41 (0.35–0.48)
SSNS/MCD	2.29 (2.18–2.40)	5.44 (4.69–6.32)	2.68 (2.52–2.86)	1.90 (1.76–2.04)
SRNS/FSGS	1.96 (1.86–2.06)	4.46 (3.35–5.94)	2.18 (2.04–2.34)	1.73 (1.60–1.87)
INS-unspecified	1.18 (1.11–1.27)	3.85 (3.00–4.93)	1.35 (1.24–1.48)	1.02 (0.92–1.13)
IgA nephropathy	5.26 (5.10–5.43)	15.02 (5.64–40.01)	7.32 (7.04–7.60)	3.21 (3.03–3.40)
Membranous Nephropathy	2.85 (2.73–2.98)	5.98 (5.19–6.90)	3.78 (3.59–3.99)	1.92 (1.79–2.07)
MGRS	0.20 (0.17–0.23)	0.81 (0.47–1.39)	0.21 (0.16–0.26)	0.19 (0.15–0.24)
MPGN/C3GN	1.29 (1.21–1.38)	4.44 (0.62–31.50)	1.35 (1.23–1.47)	1.24 (1.13–1.36)
Pregnancy	0.94 (0.88–1.02)	7.45 (6.22–8.94)		1.89 (1.75–2.03)
Retroperitoneal fibrosis	0.15 (0.13–0.19)	0.96 (0.40–2.31)	0.20 (0.16–0.25)	0.11 (0.08–0.15)
STEC HUS	0.23 (0.20–0.27)	1.10 (0.57–2.11)	0.22 (0.18–0.28)	0.24 (0.19–0.29)
ANCA-associated vasculitis	2.67 (2.56–2.79)	7.51 (5.48–10.27)	2.80 (2.63–2.98)	2.55 (2.39–2.72)
Anti-GBM disease	0.16 (0.13–0.19)	0.96 (0.36–2.55)	0.16 (0.12–0.20)	0.16 (0.13–0.21)
Other Vasculitides	2.72 (2.60–2.84)	13.08 (11.23–15.25)	2.74 (2.58–2.92)	2.69 (2.53–2.87)

ADPKD, autosomal dominant polycystic kidney disease; ADTKD, autosomal dominant tubulointerstitial kidney disease; aHUS, atypical hemolytic uremic syndrome; ANCA, antineutrophil cytoplasmic antibody; ARPKD/NPHP, autosomal recessive polycystic kidney disease and nephronophthisis; C3GN, C3 glomerulopathy; FSGS, focal segmental glomerulosclerosis; GBM, glomerular basement membrane; INS, idiopathic nephrotic syndrome; MCD, minimal change disease; MGRS, monoclonal gammopathy of renal significance; MPGN, membranoproliferative glomerulonephritis; RaDaR, National Registry of Rare Kidney Diseases; RDG, rare disease group; SRNS, steroid resistant nephrotic syndrome; SSNS, steroid sensitive nephrotic syndrome; STEC HUS, Shiga toxin/verotoxin-producing *Escherichia coli*-associated hemolytic uremic syndrome; TBMN, thin basement membrane nephropathy.

^aEstimates on July 25, 2022.

compared to adults (Supplementary Tables S10 and S12).

Renal Function of the RaDaR patient population

Many patients in RaDaR had reached KF (CKD stage G5 or KRT) (39%) (Table 3). This proportion varied by RDG; only 2% of patients with cystinuria had reached KF compared to 73% of male patients with Alport syndrome. Most pediatric patients had estimated glomerular filtration rate results >60 ml/min per 1.73 m² (71% CKD stages G1–G2 vs. 32% of adult patients).

Recruitment to RaDaR

Geographic distribution of recruitment to RaDaR across the UK is shown in Figure 3. Comparison of RaDaR with UKRR rare disease KRT populations (Figure 4 and Supplementary Table S13) demonstrated similar distributions in both populations, and statistical testing did not show significant evidence of differences (Cramer's V = 0.07).

Overall, patients recruited to RaDaR with KF were less likely to be Asian (7% vs. 9%, $P < 0.0001$) compared with unrecruited patients in the UKRR dataset (Table 4). However, there was no significant difference between the ethnic distribution of recruited versus unrecruited patients in the following RDGs: autosomal recessive polycystic kidney disease and nephronophthisis ($\text{Chi}^2 P = 0.41$), Alport syndrome ($P = 0.76$), atypical hemolytic uremic syndrome ($P = 0.55$), cystinosis ($P = 0.71$), primary hyperoxaluria ($P = 0.49$), membranoproliferative glomerulonephritis and C3 glomerulopathy ($P = 0.15$), Shiga toxin/verotoxin-producing *Escherichia coli*-associated hemolytic uremic syndrome ($P = 0.62$), and membranous nephropathy ($P = 0.44$). UKRR patients in the least deprived quintile were more likely to be recruited to RaDaR than those in the most deprived quintile (21% vs. 17%, $P < 0.0001$).

Results comparing recruitment to RaDaR at 2 large renal centers were conflicting; comparing recruited and nonrecruited but eligible patients at each center,

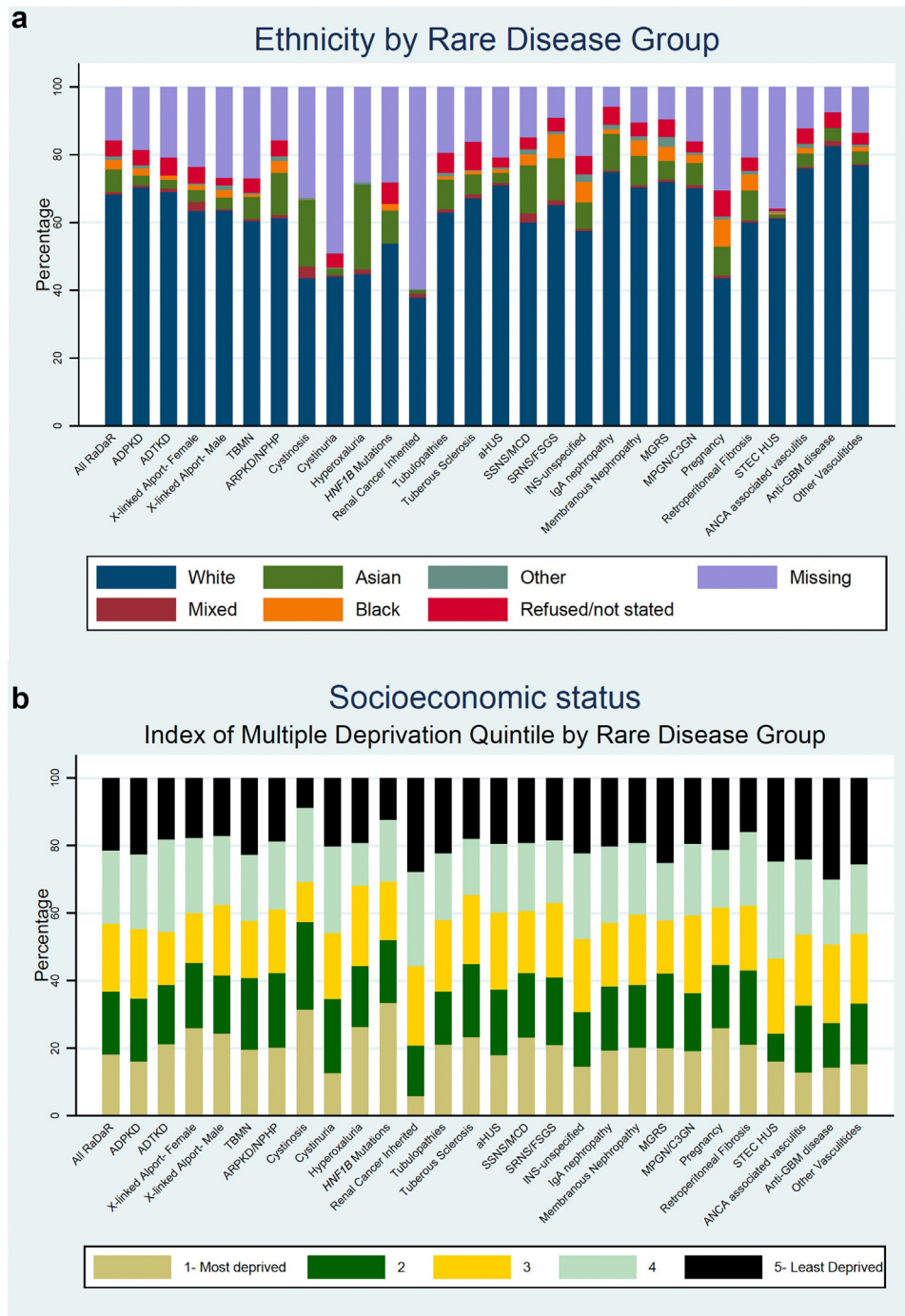


Figure 2. RaDaR patient (a) ethnicity and (b) socioeconomic status, stratified by rare disease group. ADPKD, autosomal dominant polycystic kidney disease; ADTKD, autosomal dominant tubulointerstitial kidney disease; aHUS, atypical hemolytic uremic syndrome; ANCA, antineutrophil cytoplasmic antibody; ARPKD/NPHP, autosomal recessive polycystic kidney disease and nephronophthisis; C3GN, C3 glomerulopathy; FSGS, focal segmental glomerulosclerosis; GBM, glomerular basement membrane; INS, idiopathic nephrotic syndrome; IQR, interquartile range; MCD, minimal change disease; MGRS, monoclonal gammopathy of renal significance; MPGN, membranoproliferative glomerulonephritis; NR, not reported; RaDaR, National Registry of Rare Kidney Diseases; SRNS, steroid resistant nephrotic syndrome; SSNS, steroid sensitive nephrotic syndrome; STEC HUS, Shiga toxin/verotoxin-producing Escherichia coli-associated hemolytic uremic syndrome; TBMN, thin basement membrane nephropathy.

and excluding patients with ethnicity not recorded, there were no differences in ethnicity observed in 1 center (recruited vs. nonrecruited; White, 62% vs. 64%; Mixed, 2% vs. 0%; Asian, 13% vs. 11%; Black,

20% vs. 22%; Other ethnicity, 4% vs. 4%; $P < 0.23$), evidence of overrecruitment of White (67% vs. 57%, $P < 0.0001$), and underrecruitment of Black patients (8% vs. 14%, $P < 0.0001$) in the other center.

Table 3. Chronic kidney disease stage and median eGFR of RaDaR patients on January 1, 2022

Rare disease group	CKD Stage												Median eGFR ^a			
	G1		G2		G3a		G3b		G4		G5				RRT	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	(IQR)	
ADPKD	831	(13.4)	882	(14.3)	451	(7.3)	554	(9.0)	502	(8.1)	214	(3.5)	2753	(44.5)	60	(33.7–88.9)
ADTKD	16	(10.2)	11	(7.0)	13	(8.3)	14	(8.9)	15	(9.6)	3	(1.9)	85	(54.1)	47	(30.3–82.2)
X-linked Alport- female	76	(35.3)	27	(12.6)	13	(6.0)	11	(5.1)	6	(2.8)	6	(2.8)	76	(35.3)	93	(59.8–117.0)
X-linked Alport- male	43	(13.2)	17	(5.2)	6	(1.8)	12	(3.7)	8	(2.5)	3	(0.9)	237	(72.7)	88	(43.9–121.4)
TBMN	54	(41.2)	28	(21.4)	10	(7.6)	7	(5.3)	7	(5.3)	3	(2.3)	22	(16.8)	90	(61.4–108.7)
ARPKD/NPHP	22	(12.4)	18	(10.2)	9	(5.1)	12	(6.8)	18	(10.2)	6	(3.4)	92	(52.0)	53	(29.2–92.3)
Cystinosis	6	(4.9)	10	(8.2)	7	(5.7)	6	(4.9)	5	(4.1)	3	(2.5)	85	(69.7)	55	(35.3–78.3)
Cystinuria	119	(37.9)	133	(42.4)	34	(10.8)	13	(4.1)	5	(1.6)	3	(1.0)	7	(2.2)	81	(65.0–98.6)
Hyperoxaluria	19	(22.6)	21	(25.0)	4	(4.8)	5	(6.0)	1	(1.2)			34	(40.5)	83	(64.5–96.8)
HNFB mutations	7	(14.3)	8	(16.3)	9	(18.4)	4	(8.2)	8	(16.3)	1	(2.0)	12	(24.5)	55	(31.3–79.3)
Tubulopathies	118	(53.4)	45	(20.4)	15	(6.8)	12	(5.4)	2	(0.9)	2	(0.9)	27	(12.2)	100	(72.8–116.9)
Tuberous sclerosis complex	70	(45.8)	31	(20.3)	14	(9.2)	11	(7.2)	4	(2.6)	3	(2.0)	20	(13.1)	91	(61.5–111.0)
aHUS	32	(16.0)	23	(11.5)	9	(4.5)	4	(2.0)	9	(4.5)	5	(2.5)	118	(59.0)	81	(47.5–108.3)
SSNS/MCD	672	(54.9)	304	(24.8)	91	(7.4)	51	(4.2)	18	(1.5)	4	(0.3)	84	(6.9)	97	(74.4–118.5)
SRNS/FSGS	315	(24.3)	180	(13.9)	87	(6.7)	66	(5.1)	67	(5.2)	33	(2.5)	547	(42.2)	81	(47.7–108.1)
INS-unspecified	163	(22.6)	143	(19.8)	44	(6.1)	43	(6.0)	37	(5.1)	10	(1.4)	282	(39.1)	78	(52.9–101.4)
IgA nephropathy	264	(7.6)	303	(8.7)	231	(6.7)	288	(8.3)	294	(8.5)	89	(2.6)	2000	(57.7)	49	(29.5–80.1)
Membranous Nephropathy	247	(14.3)	453	(26.2)	229	(13.2)	211	(12.2)	160	(9.2)	55	(3.2)	376	(21.7)	61	(39.4–83.4)
MGRS	1	(0.8)	14	(11.9)	12	(10.2)	17	(14.4)	8	(6.8)	8	(6.8)	58	(49.2)	42	(29.5–58.5)
MPGN/C3GN	135	(16.9)	81	(10.1)	43	(5.4)	49	(6.1)	35	(4.4)	16	(2.0)	441	(55.1)	72	(41.0–108.0)
Pregnancy	231	(37.1)	89	(14.3)	33	(5.3)	33	(5.3)	15	(2.4)	7	(1.1)	214	(34.4)	96	(67.2–115.8)
Retroperitoneal Fibrosis	9	(10.6)	25	(29.4)	20	(23.5)	12	(14.1)	4	(4.7)	4	(4.7)	11	(12.9)	57	(43.2–75.6)
STEC HUS	6	(13.6)	2	(4.5)	3	(6.8)	1	(2.3)	4	(9.1)			28	(63.6)	66	(34.7–123.9)
ANCA-associated vasculitis	111	(7.3)	308	(20.1)	278	(18.2)	252	(16.5)	200	(13.1)	35	(2.3)	346	(22.6)	50	(33.6–69.0)
Anti-GBM disease	5	(4.5)	1	(0.9)	3	(2.7)	4	(3.6)	3	(2.7)	1	(0.9)	95	(84.8)	47	(31.1–96.6)
Other vasculitides	156	(11.8)	260	(19.6)	184	(13.9)	183	(13.8)	131	(9.9)	30	(2.3)	380	(28.7)	56	(36.1–78.9]
Total	3673	(17.2)	3402	(16.0)	1849	(8.7)	1869	(8.8)	1565	(7.3)	544	(2.6)	8401	(39.4)		
Pediatric (Total)	471	(62.1)	68	(9.0)	15	(2.0)	11	(1.4)	12	(1.6)	5	(0.7)	177	(23.3)		
Adults (Total)	3202	(15.6)	3334	(16.2)	1834	(8.9)	1858	(9.0)	1553	(7.6)	539	(2.6)	8224	(40.0)		

ADPKD, autosomal dominant polycystic kidney disease; ADTKD, autosomal dominant tubulointerstitial kidney disease; aHUS, atypical hemolytic uremic syndrome; ANCA, antineutrophil cytoplasmic antibody; ARPKD/NPHP, autosomal recessive polycystic kidney disease and nephronophthisis; C3GN, C3 glomerulopathy; CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate; FSGS, focal segmental glomerulosclerosis; GBM, glomerular basement membrane; INS, idiopathic nephrotic syndrome; IQR, interquartile range; KRT, kidney replacement therapy; MCD, minimal change disease; MGRS, monoclonal gammopathy of renal significance; MPGN, membranoproliferative glomerulonephritis; RaDaR, National Registry of Rare Kidney Diseases; RDG, rare disease group; SRNS, steroid resistant nephrotic syndrome; SSNS, steroid sensitive nephrotic syndrome; STEC HUS, Shiga toxin/verotoxin-producing *Escherichia coli*-associated hemolytic uremic syndrome; TBMN, thin basement membrane nephropathy.

^aMedian eGFR of patients not receiving KRT. Inherited renal cancers have been excluded from this table due to poor data completeness. For overall, pediatric, and adult totals individuals with 2 diagnoses included once. For RDG totals individuals with 2 diagnoses included for each diagnosis.

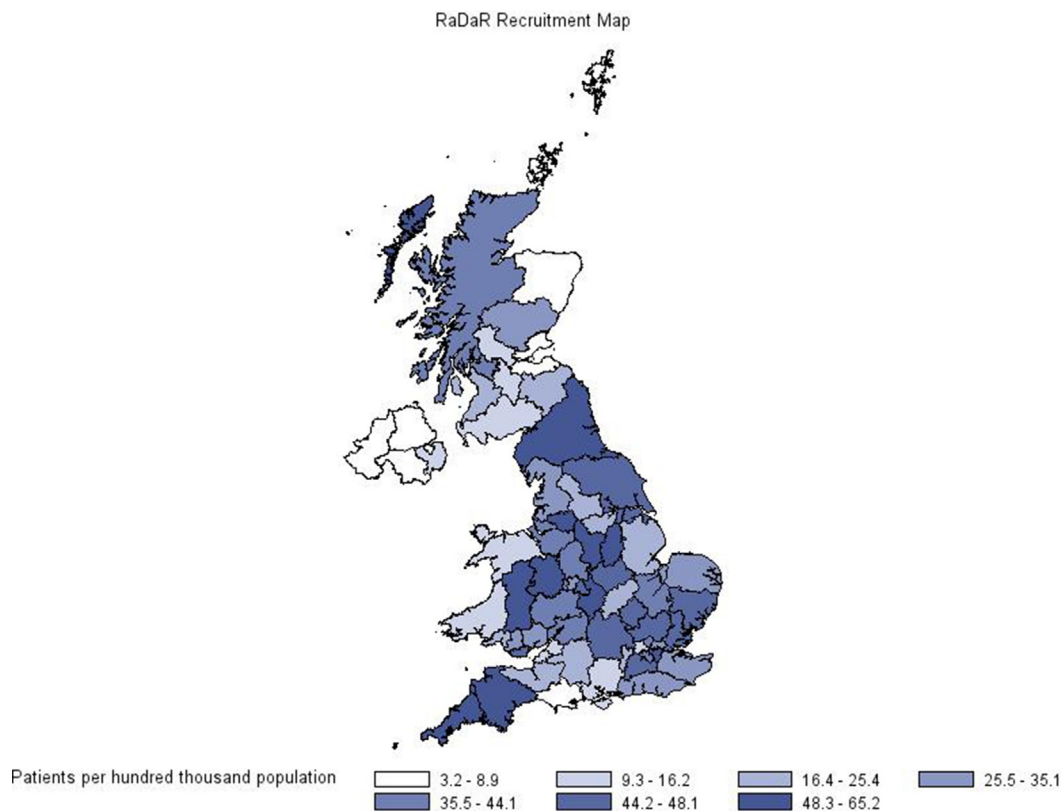


Figure 3. Distribution of recruitment to RaDaR across the United Kingdom. RaDaR, National Registry of Rare Kidney Diseases.

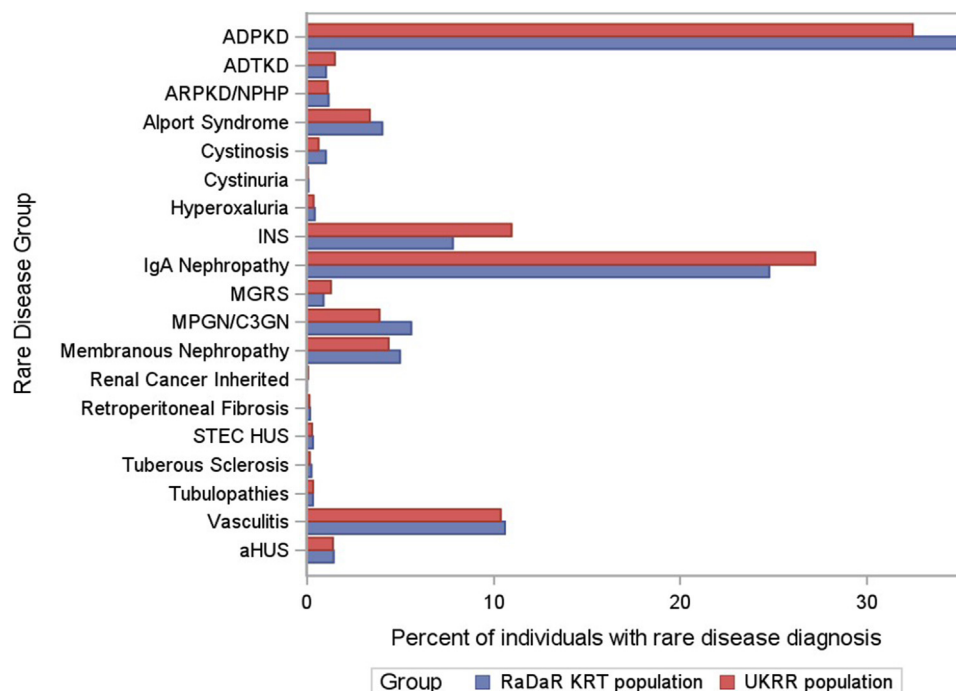


Figure 4. Proportion of rare disease diagnoses for each disorder within UKRR and RaDaR KRT recipients. ADPKD, autosomal dominant polycystic kidney disease; ADTKD, autosomal dominant tubulointerstitial kidney disease; aHUS, atypical hemolytic uremic syndrome; ANCA, antineutrophil cytoplasmic antibody; ARPKD/NPHP, autosomal recessive polycystic kidney disease and nephronophthosis; C3GN, C3 glomerulopathy; FSGS, focal segmental glomerulosclerosis; GBM, glomerular basement membrane; INS, idiopathic nephrotic syndrome; IQR, interquartile range; KRT, kidney replacement therapy; MCD, minimal change disease; MGRS, monoclonal gammopathy of renal significance; MPGN, membranoproliferative glomerulonephritis; NR, not reported; RaDaR, National Registry of Rare Kidney Diseases; SRNS, steroid resistant nephrotic syndrome; SSNS, steroid sensitive nephrotic syndrome; STEC HUS, Shiga toxin/verotoxin-producing Escherichia coli-associated hemolytic uremic syndrome; TBMN, thin basement membrane nephropathy; UKRR, UK Renal Registry.

Table 4. Ethnicity and socioeconomic status comparisons between RaDaR recruited versus unrecruited patients with rare kidney diagnoses at 2 UK renal units and between recruited patients with kidney failure and UKRR patients with rare kidney diseases

Ethnicity				Socioeconomic status (Index of Multiple Deprivation Quintiles)											
Unit 1															
	All eligible patients		Recruited to RaDaR		Not recruited to RaDaR		P-value		All eligible patients		Recruited to RaDaR		Not recruited to RaDaR		P-value
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)			n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	
White	2234 (58)	473 (67)	1761 (57)	$P < 0.0001$				1- most deprived	719 (16)	158 (12)	561 (18)	$P < 0.0001$			
Mixed	114 (3)	19 (3)	95 (3)					2	1,167 (26)	312 (24)	855 (27)				
Asian	625 (16)	122 (17)	503 (16)					3	1,044 (23)	302 (23)	742 (24)				
Black	483 (13)	56 (8)	427 (14)					4	845 (19)	282 (22)	563 (18)				
Other	366 (10)	41 (6)	325 (10)					5- least deprived	675 (15)	255 (19)	420 (13)				
Total	3822 (100)	711 (100)	3111 (100)					Total	4450 (100)	1309 (100)	3141 (100)				
Unit 2															
	All eligible patients		Recruited to RaDaR		Not recruited to RaDaR		P-value		All eligible patients		Recruited to RaDaR		Not recruited to RaDaR		P-value
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)			n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	
White	774 (63)	199 (62)	575 (64)	$P = 0.23$				1- most deprived	292 (18)	92 (19)	200 (18)	$P = 0.67$			
Mixed	9 (1)	5 (2)	4 (0)					2	442 (28)	138 (28)	304 (28)				
Asian	138 (11)	41 (13)	97 (11)					3	366 (23)	122 (25)	244 (22)				
Black	260 (21)	64 (20)	196 (22)					4	268 (17)	82 (17)	186 (17)				
Other	47 (4)	14 (4)	33 (4)					5- least deprived	223 (14)	61 (12)	162 (15)				
Total	1228 (100)	323 (100)	905 (100)					Total	1591 (100)	495 (100)	1096 (100)				
UK Renal Registry comparison															
	All eligible patients		Recruited to RaDaR		Not recruited to RaDaR		P-value		All eligible patients		Recruited to RaDaR		Not recruited to RaDaR		P-value
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)			n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	
White	21986 (85)	5655 (87)	16331 (86)	$P < 0.0001$				1- most deprived	5507 (22)	1152 (18)	4355 (23)	$P < 0.0001$			
Mixed	244 (1)	73 (1)	171 (1)					2	5519 (22)	1260 (20)	4259 (23)				
Asian	2235 (9)	468 (7)	1767 (9)					3	5462 (22)	1357 (21)	4105 (22)				
Black	1080 (4)	250 (4)	830 (4)					4	4153 (16)	1355 (21)	2798 (15)				
Other	338 (1)	74 (1)	264 (1)					5- least deprived	4589 (18)	1339 (21)	3250 (17)				
Total	25883 (100)	6520 (100)	19363 (100)					Total	25230 (100)	6463 (100)	18767 (100)				

UKRR, UK Renal Registry; RaDaR, National Registry of Rare Kidney Diseases.

Similarly, there was no evidence of difference in social deprivation in 1 center (recruited vs. non recruited; IMD quintile 1-most deprived: 19% vs. 18%, quintile 2: 28% vs. 28%, quintile 3: 25% vs. 22%, quintile 4: 17% vs. 17%, quintile 5-least deprived: 12% vs. 15%, $P < 0.67$), whereas there was evidence of overrecruitment of patients in the least deprived quintile (19% vs. 13%, $P < 0.0001$) in the other.

Prevalent English patients with a diagnosis of ADPKD were compared with the 2011 English Census, adjusted for age (Supplementary Figure S5). Deviation from the ethnic distribution of the English population varied by age group. More patients aged <40 years were White than the general population (0–17 years: 83% vs. 79%, $P = 0.006$; 18–29 years: 92% vs. 81%, $P = 0.001$; 30–39 years, 92% vs. 81%, $P < 0.0001$). However, patients aged 60 to 69 years were more likely to be Black than the general population (3% vs. 1%, $P < 0.0001$). There was no difference in ethnic distribution for individuals aged >80 years ($P = 0.39$).

DISCUSSION

We have presented cross-sectional analyses for 1934 (7%) pediatric and 23,946 (93%) adult patients with rare kidney diseases enrolled into RaDaR. To our knowledge, this is the largest epidemiological description of rare kidney diseases worldwide.

RaDaR is not a population-based registry; and therefore, cannot offer precise incidence or prevalence data on individual rare kidney disorders. However, RaDaR patient numbers have allowed us to provide minimum point prevalence UK estimates for 27 RDGs (Table 2), in some cases, for the first time. In addition, patient numbers and demographics may be useful in assessing feasibility of studies or clinical trials in individual rare kidney diseases. Comparison of RaDaR KRT recipients with UK recipients of KRT with a rare disease recorded in UKRR indicated that a similar proportion (approximately 40%) of all patients with eligible rare diseases with KF were enrolled in RaDaR, indicating that in this group, RaDaR allows comparison

of prevalence of the relevant diseases without detectable bias according to disease (Figure 4). Similar analyses could not be done in the non-KRT population because there is no comprehensive registry in this group to compare with.

After comparison with multiple data sources, we found that though there was likely to be imperfect representation of all socioeconomic and ethnic groups in RaDaR, these biases do not appear to be of a magnitude likely to distort inferences about epidemiology or natural history of RaDaR diseases. Although patients with KF in RaDaR are more likely to be White than eligible patients in the UKRR (87% vs. 85%, P -value < 0.0001), comparison of the English RaDaR ADPKD cohort with the English census and comparison with patients at 2 large renal units found no consistent ethnic recruitment bias to RaDaR. For 7 RDGs (autosomal recessive polycystic kidney disease and nephronophthisis, Alport syndrome, atypical hemolytic uremic syndrome, Shiga toxin/verotoxin-producing *Escherichia coli*-associated hemolytic uremic syndrome, cystinosis, primary hyperoxaluria, membranoproliferative glomerulonephritis and C3 glomerulopathy, and membranous nephropathy) patients with KF recruited to RaDaR closely matched the ethnic distribution of patients in the UKRR. Patients recruited to RaDaR were more likely to be from the least deprived quintile compared to the UKRR (21% vs. 18%, P -value < 0.0001), whereas there was no evidence of overrecruitment of patients in the least deprived quintile within a large renal unit (12% vs. 14%, P -value = 0.67). Future work will include investigating these differences to identify potential inequity and to target future recruitment strategies.

Despite evidence that patients of White ethnicities may be overrepresented in the RaDaR KF population, we found patients with cystinosis and primary hyperoxaluria were less likely to be White (48% and 45%, respectively vs. 70%), and more likely to be from Asian backgrounds (16% and 25% respectively vs. 6%) compared to the overall ethnic distribution of RaDaR. These differences were also present when stratified by pediatric and adult RaDaR patients, although pediatric data should be interpreted with caution due to the small patient numbers. This ethnic predisposition has been previously reported in cystinosis, with a high birth frequency rate (1:3600) reported in Pakistani ethnic groups in the West Midlands.¹⁸ However, to our knowledge it has not previously been reported in primary hyperoxaluria. Previous population analyses have suggested primary hyperoxaluria is 3 times more prevalent among European Americans than African Americans,¹⁹ and that certain PH1 gene (AGXT) variants have a strong association with people from Spanish or North

African backgrounds.²⁰ Although a possible mutational hotspot in PH3 gene HOGA1 has been identified in the Chinese population,²¹ none of the patients in the RaDaR primary hyperoxaluria cohort were from a Chinese background. As for any autosomal recessive diseases, the frequency of consanguinity in the community may impact on the incidence of cystinosis and primary hyperoxaluria. Differences in disease frequency in different self-reported ethnic groups suggest that genetic ancestry could influence the likelihood of certain diseases explaining a patient's symptoms and, whereas the differences described here do not seem large enough to justify targeted population screening, awareness of these differences may help clinicians better investigate patients. It should also be noted that in the absence of genomic data, inferences linking self-reported ethnicity (as ascertained in this study) with genetic ancestry should be made with caution.

Pediatric patients were more likely to be from Asian backgrounds compared to adults. This is likely due to the higher proportion of idiopathic nephrotic syndrome in the pediatric group (44% children vs. 13% adults), conditions that have been reported to affect South Asians up to 5 times more frequently than Europeans.^{22,23}

More pediatric patients were in the lowest IMD quintile compared to adults. In the UK, children are more likely to live in more deprived areas compared to adults, and people of Asian and Black ethnicity are more likely to live in areas with the worst levels of social deprivation than those of White ethnicity.²⁴ However, the proportion of English children recruited to RaDaR living in the most deprived IMD quintile exceeded that of children in the general English population. Differences in ethnicity and the proportion of monogenic and nonmonogenic conditions between the pediatric and adult RaDaR populations do not completely explain this disparity; children from White (24.8% vs. 16.2%, P -value < 0.001), Asian (53.5% vs. 31.1%, P -value < 0.0001), and Other (50.0% vs. 24.7%, P -value = 0.017) ethnicities were all more likely to live in more socially deprived areas than adults, as were children diagnosed with both monogenic (30.5% vs. 16.1%, P -value < 0.0001) and nonmonogenic (30.2% vs. 18.2%, P -value < 0.0001) disorders. Pediatric patients may be more intensively recruited to RaDaR from centers in areas of worst deprivation, either due to clinician interest or a higher population prevalence of certain rare kidney diseases in those areas. However, rare diseases are associated with a high economic burden for patients, especially for families with children,²⁵ perhaps explained by the additional caring responsibilities imposed on adults responsible for a child (or children) affected by a rare kidney disease reducing their capacity to earn money

(for example, owing to frequent hospital visit attendances for appointments or dialysis). In addition, children from socioeconomically deprived backgrounds experience poorer health outcomes,^{26,27} and there is evidence of reduced access to preemptive kidney transplantation in UK pediatric kidney patients from more deprived areas.²⁸ These findings therefore highlight that children with rare kidney diseases recruited to RaDaR are a potentially highly vulnerable group; further investigation is needed to determine whether they experience different outcomes.

Limitations of this study include the fact that RaDaR is a UK registry and is representative of the mainly White UK population and may not be generalizable to other ethnicities. Survivor bias may have had an impact on the enrolment of individuals with diagnoses made before RaDaR started recruiting patients with that condition. Some RaDaR diagnoses are poorly captured by European Renal Association-European Dialysis and Transplant Association primary renal diagnosis codes, which limited comparison to UKRR data. Entry of rare disease diagnoses into renal information technology systems is user-dependent and may vary between renal units used for comparisons. Although bias could be introduced owing to the variation in recruitment between centers across the UK, and therefore by variation in their catchment population, we sought to minimize effects of this bias by comparing ethnicity and socioeconomic status of each RDG to the overall RaDaR breakdown. Caution must still be exercised where clinicians with particular interest in a certain RDG recruit more intensively into that one RDG compared to others.

In summary, to our knowledge RaDaR is the largest registry of rare kidney diseases worldwide and provides numerous opportunities to advance understanding of rare kidney diseases, including identification of potential participants in clinical trials.

APPENDIX

List of the National Registry of Rare Kidney Diseases (RaDaR) Consortium

Sharirose Abat,¹ Shazia Adalat,² Joy Agbonmwandolor,³ Zubaidah Ahmad,⁴ Abdulfattah Alejmi,⁵ Rashid Almasarwah,⁶ Nicholas Annear,¹ Ellie Asgari,⁴ Amanda Ayers,⁷ Jyoti Baharani,⁸ Gowrie Balasubramaniam,⁹ Felix Jobamba Kpodo,¹⁰ Tarun Bansal,¹¹ Alison Barratt,¹² Jonathan Barratt,⁷⁹ Megan Bates,¹³ Natalie Bayne,¹⁴ Janet Bendle,¹⁵ Sarah Benyon,¹⁶ Carsten Bergmann,^{17,18} Sunil Bhandari,¹⁹ Coralie Bingham,²⁰ Preetham Boddana,²¹ Sally Bond,²² Fiona Braddon,²³ Kate Bramham,²³ Angela Branson,¹⁵ Stephen Brearey,²⁴ Vicky Brocklebank,²⁵ Sharanjit Budwal,²⁶ Conor Byrne,²⁷ Hugh Cairns,²⁸ Brian Camilleri,²⁹

Gary Campbell³⁰, Alys Capell³¹, Margaret Carmody,⁸ Marion Carson³², Tracy Cathcart,¹⁹ Christine Catley,⁹ Karine Cesar³³, Melanie Chan,⁶ Houda Chea,¹⁵ James Chess³⁴, Chee Kay Cheung,²⁶ Katy-Jane Chick³⁵, Nihil Chitalia³⁶, Martin Christian³⁷, Tina Chrysochou^{38,39}, Katherine Clark⁴⁰, Christopher Clayton⁴¹, Rhian Clissold,²⁰ Helen Cockerill³³, Joshua Coelho⁴², Elizabeth Colby⁴³, Viv Colclough⁴⁴, Eileen Conway⁴⁵, H. Terence Cook⁴⁶, Wendy Cook⁴⁷, Theresa Cooper⁴⁸, Richard J Coward⁴³, Sarah Crosbie,²² Gabor Cserep⁴⁹, Anjali Date⁵⁰, Katherine Davidson⁴⁸, Amanda Davies⁵¹, Neeraj Dhaun⁵², Ajay Dhaygude⁵³, Lynn Diskin,¹² Abhijit Dixit^{41,54}, Eunice Ann Doctolero³⁵, Suzannah Dorey⁵⁵, Lewis Downard,²³ Mark Drayson⁵⁶, Gavin Dreyer,²⁷ Tina Dutt⁵⁷, Kufreabasi Etuk,²⁸ Dawn Evans⁵⁸, Jenny Finch²⁹, Frances Flinter⁵⁹, James Fotheringham⁶⁰, Lucy Francis⁸², Daniel P. Gale⁶¹, Hugh Gallagher⁶², David Game,⁴ Eva Lozano Garcia⁴², Madita Gavrila,²² Susie Gear⁶³, Colin Geddes⁶⁴, Mark Gilchrist⁶⁵, Matt Gittus⁶⁶, Paraskevi Gogolidou⁶⁷, Christopher Goldsmith⁵⁷, Patricia Gooden⁶⁸, Andrea Goodlife,²⁶ Priyanka Goodwin⁵³, Tassos Grammatikopoulos,^{28,69} Barry Gray⁷⁰, Megan Griffith⁴⁶, Steph Gumus,⁹ Sanjana Gupta⁷¹, Patrick Hamilton⁷², Lorraine Harper⁵⁶, Tess Harris⁷³, Louise Haskell⁷⁴, Samantha Hayward⁴³, Shivaram Hegde⁷⁵, Bruce Hendry⁷⁶, Sue Hewins⁷⁷, Nicola Hewitson⁷⁸, Kate Hillman,¹⁵ Mrityunjay Hiremath⁵⁷, Alexandra Howson⁷⁹, Zay Htet,²⁸ Sharon Huish,¹⁶ Richard Hull,¹ Alister Humphries⁶⁸, David P. J. Hunt¹¹⁹, Karl Hunter⁸⁰, Samantha Hunter,¹⁹ Marilyn Ijeomah-Orji,⁶ Nick Inston⁸¹, David Jayne⁸², Gbemisola Jenfa³¹, Alison Jenkins⁸³, Sally Johnson¹¹⁸, Caroline A Jones⁸⁴, Colin Jones⁸⁵, Amanda Jones,⁵ Rachel Jones⁸², Lavanya Kamesh⁸¹, Durga Kanigicherla³⁹, Fiona Karet Frankl⁸², Mahzuz Karim⁸⁶, Amrit Kaur⁸⁷, David Kavanagh,²⁵ Kelly Kearley⁸⁸, Larissa Kerecuk,¹⁴ Arif Khwaja⁷⁰, Garry King,²³ Grant King⁸⁹, Ewa Kislowska,⁴ Edyta Klata²⁹, Maria Kokocinska,¹⁴ Mark Lambie⁹⁰, Laura Lawless⁴¹, Thomas Ledson⁸⁰, Rachel Lennon⁹¹, Adam P Levine⁹², Ling Wai Maggie Lai,¹⁶ Graham Lipkin⁸¹, Graham Lovitt⁹³, Paul Lyons⁹⁴, Holly Mabillard⁹⁵, Katherine Mackintosh,⁷ Khalid Mahdi⁹⁶, Eamonn Maher⁹⁷, Kevin J. Marchbank,²⁵ Patrick B Mark⁶⁴, Sherry Masoud,²³ Bridgett Masunda,⁹ Zainab Mavani³¹, Jake Mayfair,⁴ Stephen McA-doo,⁶ Joanna Mckinnell⁹⁸, Nabil Melhem,² Simon Meyrick⁵¹, Shabbir Moochhala⁶¹, Putnam Morgan⁹⁹, Ann Morgan^{100,101}, Fawad Muhammad,⁵ Shona Murray³⁰, Kristina Novobritskaya,²² Albert CM Ong^{66,70}, Louise Oni¹⁰², Kate Osmaston,²³ Neal Padmanabhan⁶⁴, Sharon Parkes,¹⁴ Jean Patrick,⁷ James Pattison,⁴ Riny Paul,¹ Rachel Percival¹⁰³, Stephen J. Perkins¹⁰⁴, Alexandre Persu^{105,106}, William G Petchey¹⁰⁷, Matthew C. Pickering⁴⁶, Jennifer Pinney⁸¹, David Pitcher,²³ Lucy Plumb⁴³, Zoe Plummer,²³ Joyce Popoola,¹ Frank Post,²⁸ Albert Power⁸³, Guy Pratt⁵⁶, Charles Pusey⁴⁶, Ria Rabara,²² May Rabuya,⁴ Tina Raju⁴², Chadd Javier¹⁰⁸, Ian SD Roberts,²² Candice Roufosse¹⁰⁹, Adam Rumjon,²⁸ Alan Salama⁶¹, Moin Saleem⁴³, RN

Sandford⁹⁷, Kanwaljit S. Sandu¹¹⁰, Nadia Sarween⁸¹, John A. Sayer⁹⁵, Neil Sebire^{111,112}, Haresh Selvaskandan,²⁶ Sapna Shah,²⁸ Asheesh Sharma⁵⁷, Edward J Sharples,²² Neil Sheerin,²⁵ Harish Shetty⁵³, Rukshana Shroff¹¹², Roslyn Simms⁷⁰, Manish Sinha,² Smeeta Sinha¹¹³, Kerry Smith²⁹, Lara Smith,¹⁵ Shalabh Srivastava¹¹⁴, Retha Steenkamp,²³ Ian Stott¹¹⁵, Katerina Stroud⁹⁷, Pauline Swift⁴², Justyna Szklarzewicz,²⁶ Fred Tam⁴⁶, Kay Tan¹¹⁶, Robert Taylor¹¹⁷, Marc Tischkowitz⁹⁷, Kay Thomas,⁴ Yincen Tse¹¹⁸, Alison Turnbull⁸⁵, A. Neil Turner¹¹⁹, Kay Tyerman⁵⁵, Miranda Usher¹²⁰, Gopalakrishnan Venkat-Raman¹²¹, Alycon Walker¹²², Stephen B. Walsh⁶¹, Aoife Waters¹²³, Angela Watt⁶⁸, Phil Webster,⁶ Ashutosh Wechalekar¹²⁴, Gavin Iain Welsh⁴³, Nicol West¹²⁵, David Wheeler⁶¹, Kate Wiles,²⁷ Lisa Willcocks¹⁰⁷, Angharad Williams³³, Emma Williams²⁹, Karen Williams,⁴ Deborah H Wilson¹²⁶, Patricia D. Wilson¹²⁷, Paul Winyard,⁹ Edwin Wong,²⁵ Katie Wong,²³ Grahame Wood⁵⁸, Emma Woodward,¹⁵ Len Woodward¹²⁸, Adrian Woolf¹²⁹, and David Wright⁷¹

¹St George's University Hospitals NHS Foundation Trust, UK; ²Evelina London Children's Hospital, UK; ³David Evans Medical Research Centre, Nottingham University Hospital NHS Trust, UK; ⁴Guy's and St Thomas NHS foundation Trust, UK; ⁵Ysbyty Gwynedd, Betsi Cadwaladr University Health Board, UK; ⁶Imperial College Healthcare NHS Trust, UK; ⁷James Paget University Hospital NHS Foundation Trust, UK; ⁸Heart of England NHS Foundation Trust, Birmingham, UK; ⁹Mid and South Essex NHS Foundation Trust, UK; ¹⁰Royal Berkshire NHS Foundation Trust, UK; ¹¹Bradford Teaching Hospitals NHS Foundation Trust, UK; ¹²Royal United Hospital Bath NHS Trust, UK; ¹³Freeman Hospital, Newcastle Upon Tyne, UK; ¹⁴Birmingham Women's and Children's NHS Foundation Trust, UK; ¹⁵Manchester University NHS Foundation Trust, UK; ¹⁶Royal Devon University Healthcare NHS Foundation Trust, UK; ¹⁷Medizinische Genetik Mainz, Mainz, Germany; ¹⁸Department of Medicine, Faculty of Medicine, Medical Center-University of Freiburg, Freiburg, Germany; ¹⁹Hull University Teaching Hospitals NHS Trust, UK; ²⁰Exeter Kidney Unit, Royal Devon University Healthcare NHS Foundation Trust, UK; ²¹Gloucestershire Hospitals NHS Foundation Trust, UK; ²²Oxford University Hospitals NHS Foundation Trust, UK; ²³UK Kidney Association, UK; ²⁴Countess of Chester NHS Foundation Trust, UK; ²⁵National Renal Complement Therapeutics Centre, Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK; ²⁶University Hospitals of Leicester NHS Trust, UK; ²⁷Barts Health NHS Trust, London, UK; ²⁸King's College Hospital NHS Foundation Trust, UK; ²⁹East Suffolk and North Essex NHS Foundation Trust, UK; ³⁰Ninewells Hospital and Medical School, Dundee, UK; ³¹North West Anglia NHS Foundation Trust, UK; ³²Northern Health and Social Care Trust and Northern Ireland Clinical Research Network; ³³West Suffolk NHS Foundation Trust, UK;

³⁴Morrison Hospital, Swansea Bay Health Board, UK; ³⁵Lister Hospital, East and North Hertfordshire NHS Trust, UK; ³⁶Dartford and Gravesham NHS Trust, UK; ³⁷Nottingham Children's Hospital, UK; ³⁸Salford Royal Hospital, Northern Care Alliance NHS Foundation Trust, Salford, UK; ³⁹University of Manchester, UK; ⁴⁰King's College London, UK; ⁴¹Nottingham University Hospitals NHS trust, UK; ⁴²Epsom and St Helier University Hospitals NHS Trust, UK; ⁴³University of Bristol Medical School, Bristol, UK; ⁴⁴Royal Stoke University Hospital, UK; ⁴⁵Manchester Royal Infirmary, UK; ⁴⁶Centre for Inflammatory Disease, Imperial College London, UK; ⁴⁷'Nephrotic Syndrome Trust' (NeST), UK; ⁴⁸North Cumbria Integrated Care NHS Foundation Trust, UK; ⁴⁹Colchester General Hospital, UK; ⁵⁰Tameside and Glossop Integrated Care NHS Foundation Trust, UK; ⁵¹Wye Valley NHS Trust, UK; ⁵²BHF Centre for Cardiovascular Science, The Queen's Medical Research Institute, University of Edinburgh, UK; ⁵³Lancashire Teaching Hospital, UK; ⁵⁴School of Medicine, University of Nottingham, UK; ⁵⁵Leeds Teaching Hospitals NHS Trust, UK; ⁵⁶University of Birmingham, UK; ⁵⁷Liverpool University Hospitals Foundation NHS Trust, UK; ⁵⁸Salford Royal NHS Foundation Trust, UK; ⁵⁹Department of Clinical Genetics, Guy's and St Thomas' NHS Foundation Trust, UK; ⁶⁰Centre for Health and Related Research, School of Population Health, University of Sheffield, UK; ⁶¹University College London Department of Renal Medicine, Royal Free Hospital, UK; ⁶²SW Thames Renal Unit, Epsom and St Helier University Hospitals NHS Trust, UK; ⁶³Alport UK, UK; ⁶⁴Queen Elizabeth University Hospital, Glasgow, UK; ⁶⁵College of Medicine and Health, University of Exeter, UK; ⁶⁶Division of Population Health, University of Sheffield, UK; ⁶⁷University of Wolverhampton, UK; ⁶⁸Patient Representative, UK; ⁶⁹Institute of Liver Studies, King's College London, UK; ⁷⁰Sheffield Kidney Institute, Sheffield Teaching Hospitals NHS Foundation Trust, UK; ⁷¹Royal Free Hospital, UK; ⁷²Manchester Institute of Nephrology and Transplantation, Manchester Royal Infirmary, UK; ⁷³PKD Charity, UK; ⁷⁴University Hospital Southampton NHS Foundation Trust, UK; ⁷⁵Children's Kidney centre, University Hospital of Wales, UK; ⁷⁶Traverse Therapeutics, UK; ⁷⁷University Hospitals Coventry and Warwickshire NHS Trust, UK; ⁷⁸County Durham & Darlington NHS Foundation Trust, UK; ⁷⁹University of Leicester, UK; ⁸⁰Wirral University Teaching Hospital NHS Foundation Trust, UK; ⁸¹University Hospitals Birmingham NHS Foundation Trust, UK; ⁸²Department of Medicine, University of Cambridge, UK; ⁸³North Bristol NHS Trust, UK; ⁸⁴Alder Hey Childrens NHS Foundation Trust, UK; ⁸⁵York & Scarborough Teaching Hospitals NHS Foundation Trust, UK; ⁸⁶Norfolk and Norwich University Hospitals NHS Trust, UK; ⁸⁷Royal Manchester Children's Hospital, Manchester, UK; ⁸⁸PTEN UK and Ireland Patient Group; ⁸⁹HNF1B Support Group, UK; ⁹⁰School of Medicine, Keele University, UK; ⁹¹Wellcome Centre for Cell-Matrix Research, University of Manchester,

UK; ⁹²Research Department of Pathology, University College London, UK; ⁹³HLRCC Foundation, UK; ⁹⁴Cambridge Institute of Therapeutic Immunology and Infectious Disease, Cambridge, UK; ⁹⁵Newcastle University, UK; ⁹⁶United Lincolnshire Hospitals NHS Trust, UK; ⁹⁷Department of Medical Genetics, University of Cambridge, UK; ⁹⁸University Hospitals of Derby and Burton NHS Foundation Trust, UK; ⁹⁹Retroperitoneal Fibrosis (RF) Group, UK; ¹⁰⁰National Institute of Health and Care Research Leeds Biomedical Research Centre, Leeds Teaching Hospitals NHS Trust, UK; ¹⁰¹School of Medicine, University of Leeds, UK; ¹⁰²University of Liverpool, UK; ¹⁰³Newcastle Upon Tyne Hospitals NHS Foundation Trust, UK; ¹⁰⁴Research Department of Structural and Molecular Biology, University College London, UK; ¹⁰⁵Division of Cardiology, Cliniques Universitaires Saint-Luc, Belgium; ¹⁰⁶Pole of Cardiovascular Research, Institut de Recherche Expérimentale et Clinique, Université Catholique de Louvain, Brussels, Belgium; ¹⁰⁷Cambridge University Hospitals NHS Foundation Trust, UK; ¹⁰⁸East and North Hertfordshire NHS Trust, UK; ¹⁰⁹Department of Immunology and Inflammation, Faculty of Medicine, Imperial College London, UK; ¹¹⁰Shrewsbury and Telford Hospital NHS Trust, UK; ¹¹¹National Institute of Health and Care Research Great Ormond Street Hospital Biomedical Research Centre, UK; ¹¹²UCL Great Ormond Street Institute of Child Health, UK; ¹¹³Northern Care Alliance NHS Foundation Trust, UK; ¹¹⁴South Tyneside and Sunderland NHS Foundation Trust, UK; ¹¹⁵Doncaster and Bassetlaw Teaching Hospitals, UK; ¹¹⁶New Cross Hospital, Wolverhampton, UK; ¹¹⁷Wellcome Centre for Mitochondrial Research, Translational & Clinical Research Institute, Faculty of Medical Sciences, Newcastle University, UK; ¹¹⁸Great North Children's Hospital, Newcastle Upon Tyne, UK; ¹¹⁹University of Edinburgh, UK; ¹²⁰Calderdale & Huddersfield Foundation Trust, UK; ¹²¹Royal Surrey County Hospital, Guildford, UK; ¹²²South Tees Hospitals NHS Foundation Trust, UK; ¹²³University College Cork, Ireland; ¹²⁴National Amyloidosis Centre, University College London, UK; ¹²⁵Great Western Hospital, Swindon, UK; ¹²⁶North Tees and Hartlepool NHS Foundation Trust, UK; ¹²⁷University College London, UK; ¹²⁸aHUS Alliance, UK; and ¹²⁹School of Biological Sciences, University of Manchester, UK

DISCLOSURE

KTLS, KH, and JY declare employment with Pfizer Inc who part-funded the analysis. ERM declares support for the current manuscript from VHL UK/Ireland and has received fees for consulting for MSD. SM is chair of OxalEurope. MS declares support for the current manuscript from a Medical Research Council UK Precision Medicine program grant - MR/R013942/1 and has received fees for consulting for Travers Therapeutics. RJC declares support for the current

manuscript from Kidney Research UK. JAS declares support for the current manuscript from Kidney Research UK, Northern Counties Kidney Research Fund, and the Medical Research Council UK (payments to institution) and is Academic Vice President of the UK Kidney Association (UKKA). FWKT declares support from the National Institute for Health and Care Research Imperial Biomedical Centre. DN is the UKKA Director of Informatics Research. DPG declares support for the current manuscript from St Peter's Trust for Kidney Bladder and Prostate Research, Pfizer Inc, Medical Research Council, Kidney Research UK, Kidney Care UK, and Polycystic Kidney Disease Charity (payments to institution), chairs the Rare Diseases Committee of the UKKA and has received fees for consulting and presenting from Novartis, Alexion, Calliditas, Sanofi, Britannia, and Travers. All the other authors declared no competing interests.

ACKNOWLEDGMENTS

The authors thank all RaDaR participants, their family members, and the UK Renal Registry staff.

RaDaR has received support from the UK Kidney Association, the UK Medical Research Council, Kidney Research UK, Kidney Care UK, and the Polycystic Kidney Disease Charity. This work was partly supported by Pfizer Inc.

DATA AVAILABILITY

The RaDaR database is hosted by the UK Renal Registry and its metadata are available via <https://rarerenal.org>. Individual-level data are not available for export. Proposals to perform analyses using the data for academic, audit or commercial purposes can be made to the RaDaR Operations Group via <https://rarerenal.org>

AUTHOR CONTRIBUTIONS

DPG and KB conceived the study. DPG and MS acquired funding. KW and DP curated data performed formal analyses, accessed, and verified the data, and wrote the initial draft. FB, RS, LD, and SM curated data and assisted investigation. NA, JB, CB, RJC, CC, DG, SG, MH, DK, FKF, LK, ERM, SM, JP, MS, JAS, RS, SSi, SSr, FWKT, KT, ANT, AW, SBW, PW, and EW administered the project and provided resources. KTLS, KH, and JL provided methodological support. DN, DB, KB, and DPG provided methodological support and supervision. All authors except KTLS, KH, and JH had access to all the included data, reviewed, and edited the manuscript. DPG, DP, and KW had final responsibility to submit for publication.

SUPPLEMENTARY MATERIAL

[Supplementary File \(PDF\)](#)

Supplementary Methods.**Supplementary References.**

Figure S1. Comparison of ethnicity in each rare disease group.

Figure S2. Comparison of ethnicity in each rare disease group to total ethnicity breakdown of RaDaR, stratified by current (A) pediatric and (B) adult patients.

Figure S3. Comparison of IMD quintile in each rare disease group to total IMD quintile distribution of RaDaR.

Figure S4. Comparison of IMD quintile in each rare disease group to total IMD quintile distribution of RaDaR, stratified by current (A) pediatric and (B) adult patients.

Figure S5. Ethnicity of English RaDaR patients with ADPKD compared to English census.

Table S1. Missing data analysis for individuals missing date of diagnosis.

Table S2. Missing data analysis for individuals missing ethnicity.

Table S3. Missing data analysis for individuals missing IMD quintile data.

Table S4. European Renal Association-European Dialysis and Transplant Association codes and search terms for each rare disease group.

Table S5. Ethnicity and IMD quintile, * stratified by current age.

Table S6. Ethnic and IMD quintile distribution of children (aged ≤ 18 years) in England* compared to the children in RaDaR.

Table S7. Monogenic and nonmonogenic disorders, stratified by ethnicity.

Table S8. Monogenic and nonmonogenic disorders, stratified by age category* and ethnicity.

Table S9. Monogenic and nonmonogenic disorders, stratified by ethnicity and IMD quintile.

Table S10. Socioeconomic status (IMD quintile) of RaDaR participants, stratified by mode of inheritance and age category. *

Table S11. IMD quintile, stratified by current age and ethnicity.

Table S12. Socioeconomic status (IMD quintile), stratified by monogenic and nonmonogenic disorders and age category. *

Table S13. Number and percentage of rare disease diagnoses for each disorder within UKRR and RaDaR KRT recipients.

Table S14. Recruiting centers.

Table S15. RaDaR eligibility criteria.

STROBE checklist for reporting observational studies.

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