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ORIGINAL ARTICLE

Kidney replacement therapy trajectories of patients with kidney failure: an ERA Registry study

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ABSTRACT

Background. Trajectories of patients receiving kidney replacement therapy (KRT), including transitions between hemodialysis (HD), peritoneal dialysis (PD) and kidney transplantation (KTx), may vary across patient subgroups and have not yet been investigated in Europe. This study aimed to: (i) describe the number of shifts across KRT modalities; and (ii) characterize the most frequent patient trajectories, including the direction of shifts across KRT modalities, the duration spent on each modality, and patient events, including death.

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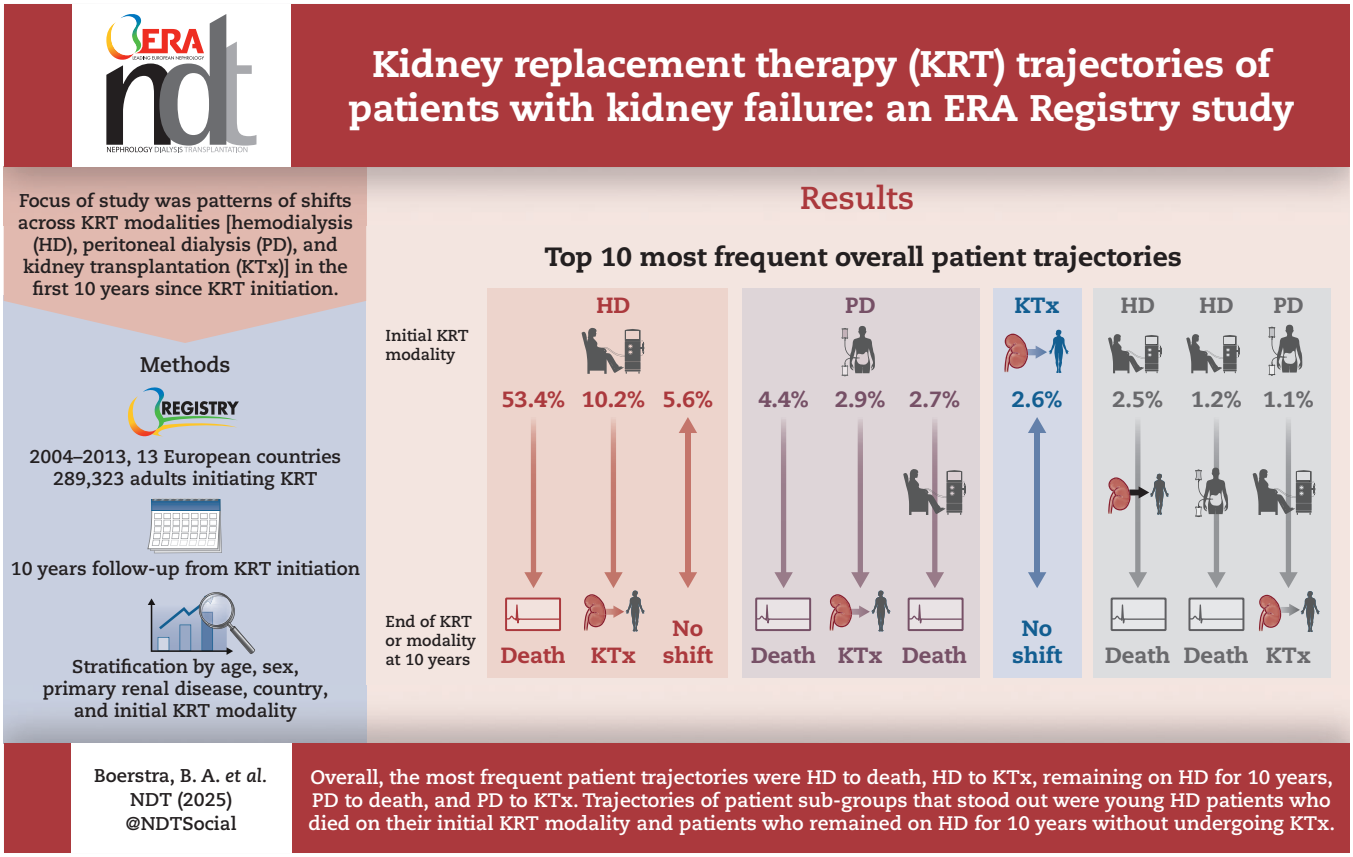
Methods. Data of adult patients (≥20 years) who initiated KRT between 2004 and 2013 were extracted from the European Renal Association (ERA) Registry database and patients were followed for 10 years from the moment of KRT initiation. Results were stratified by age, sex, primary renal disease (PRD), country and initial KRT modality.

Results. Among 289 323 patients, more than two-thirds (69.6%) remained on their initial KRT modality until death or the end of 10 years follow-up, but younger patients and patients who initiated with PD had more shifts across KRT modalities than others. Overall, the most frequent patient trajectories were HD followed by death (53.4%), HD to KTx (10.2%), remaining on HD for 10 years (5.6%), PD followed by death (4.4%) and PD to KTx (2.9%). The most frequent patient trajectories differed between age and PRD groups, and across European countries, but not between women and men.

Conclusion. The number and direction of shifts across KRT modalities varied by age, PRD, country and initial KRT modality, but not by sex. Future research should further investigate trajectories of patient subgroups that stood out, including young HD patients who died on their initial KRT modality and those who remained on HD for 10 years without undergoing KTx.

Keywords: hemodialysis, kidney transplantation, peritoneal dialysis, pre-emptive, transitions

GRAPHICAL ABSTRACT



KEY LEARNING POINTS

What was known:

- A single kidney replacement therapy (KRT) modality may not be adequate to cover the lifespan of a patient with kidney failure, prompting patients to transition between hemodialysis (HD), peritoneal dialysis (PD) and kidney transplantation (KTx).
- Through renal registries, there is substantial information available on the incidence and prevalence of HD, PD and KTx, and several studies have investigated single modality transitions, but less is known about longitudinal patient trajectories from the start of KRT.
- Trajectories of patients receiving KRT may vary across patient subgroups, such as by age, sex and primary renal disease (PRD), as well as between European countries.

This study adds:

- The number and direction of shifts across KRT modalities differed across age, PRD, country and initial KRT modality, but not by sex.
- The most common overall patient trajectories were HD followed by death, HD with a transition to KTx, initiating KRT with and remaining on HD for at least 10 years, PD followed by death and PD with a transition to KTx.
- Trajectories of some patient subgroups stood out, including young HD patients who died on their initial KRT modality and those who remained on HD for 10 years without undergoing KTx.

Potential impact:

- This study contributes to existing literature by providing a detailed overview of the most frequent patient trajectories in the first 10 years since KRT initiation in Europe, including the number and direction of shifts across KRT modalities, and the duration spent on each modality.
- Understanding KRT trajectories may help nephrologists support their patients in making more informed decisions regarding their treatment options, and may also support healthcare systems to better predict patient needs and manage resources effectively.
- Identifying trajectories of patient subgroups that stood out is informative for future work; moreover, these groups highlight the importance of evaluating kidney transplant candidacy in each patient, and supports the creation of an individualized dialysis life plan in the event that patients are not considered suitable for KTx.

INTRODUCTION

A single kidney replacement therapy (KRT) modality may not be adequate to cover the lifespan of a patient with kidney failure. Therefore, patients may transition between hemodialysis (HD), peritoneal dialysis (PD) and kidney transplantation (KTx).

Transitions between KRT modalities can occur as part of a patient's planned treatment course, while awaiting or preparing for a more suitable treatment option, or may be due to unforeseen circumstances [1, 2]. For instance, a patient may receive HD while awaiting KTx or preparing for PD, or may be forced to switch to HD if a kidney graft is lost or if PD is no longer possible due to infection, such as peritonitis or loss of peritoneal function. Trajectories of patients receiving KRT may vary across patient subgroups, such as by age, sex and primary renal disease (PRD), as well as between countries. Socioeconomic factors and local health policies in favor of certain KRT modalities may determine the availability of a treatment within a country, influencing both the initial KRT modality and subsequent transitions between modalities [3, 4].

While there is substantial information available on the incidence and prevalence of HD, PD and KTx [5–10], as well as single modality transitions [11, 12], less is known about longitudinal patient trajectories from the start of KRT. Therefore, this study aimed to: (i) describe the number of shifts across KRT modalities (HD, PD and KTx); and (ii) characterize the most frequent patient trajectories, including the direction of shifts across KRT modalities, the duration spent on each modality and patient events, such as death. Results were stratified by age, sex, PRD, country and initial KRT modality.

MATERIALS AND METHODS

Data sources

The European Renal Association (ERA) Registry annually collects data on KRT via national and regional renal registries in Europe. In this study, individual patient data of adults (≥20 years) who initiated KRT in 2004–13 were extracted from the ERA Registry database and patients were followed for 10 years from the moment of KRT initiation. For Finland, patients who initiated KRT in 2003–12 were included and followed for 10 years until 2021 as individual patient data for 2022 was not available.

Patients were included from 26 renal registries covering the following countries and regions: Austria; Dutch- and French-speaking Belgium (together providing 100% population coverage of Belgium); Bosnia and Herzegovina; Denmark; Finland; France (83% population coverage); Greece; Iceland; the Netherlands; Norway; Andalusia, Aragon, Asturias, Basque country, Cantabria, Castile and León, Castile-La Mancha, Catalonia, Extremadura, Galicia, Madrid and Valencia (together providing 95% population coverage of Spain); Sweden; England/Wales/Northern Ireland and Scotland (together providing 100% population coverage of the UK). Where applicable, results were presented at the country level.

Definitions

"Patient trajectory" refers to a patient's journey from the start of KRT until the end of KRT or censoring at 10 years, and includes "shifts across KRT modalities" (HD, PD and KTx) and patient events, including recovery of kidney function (>90 days), death, dialysis withdrawal and loss to follow-up (Supplementary data, Fig. S1).

Table 1: Distribution of initial KRT modality by age, sex, PRD and country.

	Total	HD		PD		Pre-emptive KTx	
Subgroups	N	N	Row %	N	Row %	N	Row %
Total	289 323	236 439	81.7	42 511	14.7	10 373	3.6
Age at KRT initiation							
20–44 years	34 172	22 804	66.7	7362	21.5	4006	11.7
45–64 years	88 423	67 989	76.9	15 372	17.4	5062	5.7
65–74 years	75 165	64 077	85.3	9880	13.1	1208	1.6
75+ years	91 563	81 569	89.1	9897	10.8	97	0.1
Sex							
Women	107 329	87 129	81.2	16 047	15.0	4153	3.9
Men	181 994	149 310	82.0	26 464	14.5	6220	3.4
PRD							
Diabetes	68 072	57 132	83.9	9569	14.1	1371	2.0
HTN/RVD	54 259	45 979	84.7	7630	14.1	650	1.2
Glomerulonephritis	33 310	24 475	73.5	6690	20.1	2145	6.4
ADPKD	17 793	12 483	70.2	3541	19.9	1769	9.9
Miscellaneous	64 097	53 262	83.1	8029	12.5	2806	4.4
Unknown/missing	51 792	43 108	83.2	7052	13.6	1632	3.2
Country							
Austria	12 348	11 079	89.7	1009	8.2	260	2.1
Bosnia and Herzegovina	1264	1234	97.6	29	2.3	1	0.1
Belgium	20 457	18 076	88.4	2041	10.0	340	1.7
Denmark	6917	4675	67.6	1996	28.9	246	3.6
Finland	4700	3526	75.0	1169	24.9	5	0.1
France	75 948	65 284	86.0	8344	11.0	2320	3.1
Greece	22 260	20 699	93.0	1487	6.7	74	0.3
Iceland	244	163	66.8	59	24.2	22	9.0
Netherlands	18 555	13 740	74.1	3295	17.8	1520	8.2
Norway	5068	3538	69.8	967	19.1	563	11.1
Spain	47 236	39 855	84.4	238	13.2	1143	2.4
Sweden	11 082	7190	64.9	3450	31.1	442	4.0
United Kingdom	63 244	47 380	74.9	12 427	19.7	3437	5.4

Statistical analyses

Patients were analyzed as a whole and according to their initial KRT modality (HD, PD or KTx), and results were stratified by age, sex, PRD and country where applicable. PRD reflects the 1995 ERA codes and groups [5], but hypertension and renal vascular disease were combined to form a single group named "HTN/RVD," and pyelonephritis was added to the "miscellaneous" group. Descriptive statistics were used to characterize the number and direction of shifts across KRT modalities, and the duration spent on each modality. An additional age-standardized analysis was performed for the number of shifts across KRT modalities using weights from the present study population. Furthermore, a Sankey plot was created to visualize transitions at each year of follow-up. Patients with >10 shifts across modalities were considered outliers and excluded from analyses ($n = 20$, 0.0%), as were patients with an unknown first KRT modality ($n = 2186$, 0.8%). Data were analyzed using Statistical Analysis Software (version 9.4, SAS Institute, NC, USA).

Data for the duration of follow-up and time spent on KRT modalities were left-skewed, but mean and median values were close in range due to censoring at 10 years. To increase the interpretability of results and to enable the summation of time durations, mean values were reported for any duration variables.

RESULTS

In 2004–13, a total of 289 323 patients initiated KRT among 13 participating European countries, of which 57.6% were aged ≥65 years, 62.9% were men, and 23.5% had diabetes as PRD. The majority of patients initiated KRT with HD (81.7%), while 14.7% initiated with PD, and 3.6% received a pre-emptive transplant. The distribution of initial KRT modality varied by age, PRD and country, but not by sex (Table 1).

Number of shifts across KRT modalities

More than two-thirds of patients remained on their initial KRT modality until death or the end of 10 years of follow-up (69.6%), followed by 22.1% of patients who had 1 shift and 8.3% who had 2+ shifts across modalities (Table 2).

The number of shifts across KRT modalities depended on whether patients survived the entire duration of follow-up. In patients who were alive at 10 years (30.5% of entire study population), the largest proportion experienced 1 shift to another modality, while among patients deceased at 10 years, the majority died on their initial KRT modality (Supplementary data, Fig. S2).

Number of shifts by age, sex, PRD and country

The number of shifts across KRT modalities varied by age, PRD and country, but not by sex. Younger patients and those with glomerulonephritis or autosomal dominant polycystic kidney disease (ADPKD) as PRD had more shifts across KRT modalities, though the number of shifts across PRD groups became more similar after age-standardization (Supplementary data, Table S1). Shifts across KRT modalities were most frequent in Finland and

Table 2: Number of shifts across KRT modalities by initial KRT modality and by age, sex and PRD.

	Total			HD			PD			Pre-emptive KTx		
Subgroups	**0 shifts (*N* = 201 280)**	**1 shift (*N* = 64 013)**	**2+ shifts (*N* = 24 030)**	**0 shifts (*N* = 178 528)**	**1 shift (*N* = 43 465)**	**2+ shifts (*N* = 14 446)**	**0 shifts (*N* = 13 626)**	**1 shift (*N* = 19 886)**	**2+ shifts (*N* = 8999)**	**0 shifts (*N* = 9126)**	**1 shift (*N* = 662)**	**2+ shifts (*N* = 585)**
Total, %	69.6	22.1	8.3	75.5	18.4	6.1	32.1	46.8	21.2	88.0	6.4	5.7
Age at KRT initiation, %												
20–44 years	29.6	48.6	21.8	27.4	53.3	19.3	6.0	56.9	37.1	86.1	6.3	7.5
45–64 years	52.4	34.7	12.9	57.5	32.6	9.9	18.2	53.2	28.6	89.3	5.7	5.1
65–74 years	79.5	15.3	5.3	85.3	10.7	3.9	40.4	45.4	14.3	88.8	9.3	1.9
75+ years	92.9	5.8	1.4	96.3	2.8	1.0	64.7	30.7	4.7	88.7	10.3	1.0
Sex, %												
Women	70.4	21.5	8.2	76.8	17.3	5.9	31.2	47.5	21.3	87.1	6.8	6.1
Men	69.1	22.5	8.4	74.8	19.0	6.3	32.6	46.3	21.1	88.6	6.1	5.4
PRD, %												
Diabetes	75.8	17.7	6.6	81.9	13.4	4.6	38.4	44.0	17.6	84.3	10.6	5.2
HTN/RVD	77.4	16.6	6.1	82.5	12.8	4.7	45.8	40.2	14.0	84.6	10.2	5.2
Glomerulonephritis	48.0	36.4	15.7	53.8	33.9	12.4	14.3	55.6	30.2	87.0	5.6	7.4
ADPKD	40.0	46.6	13.4	41.2	49.8	9.0	10.3	56.3	33.4	91.0	4.5	4.6
Miscellaneous	71.9	19.9	8.3	75.4	18.0	6.6	29.7	47.4	22.9	88.3	6.2	5.5
Unknown/missing	76.4	17.4	6.3	81.9	13.5	4.6	39.1	43.8	9.6	89.9	4.8	5.3

Number of shifts only reflects shifts across HD, PD and KTx. The maximum follow-up period was 10 years.

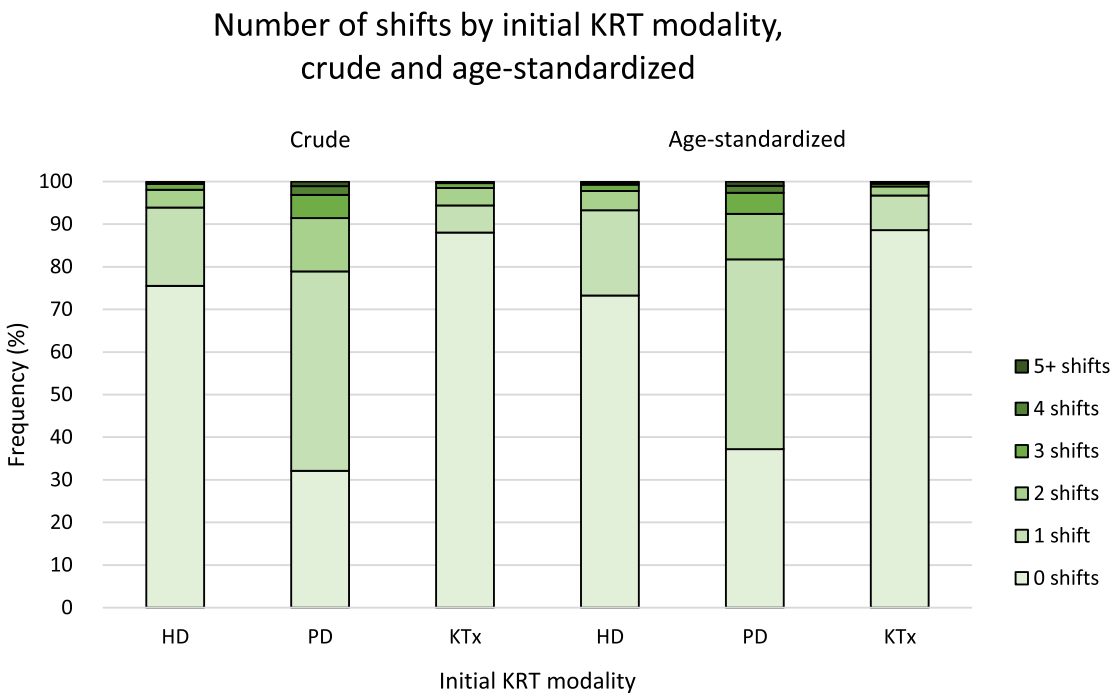


Figure 1: Crude and age-standardized number of shifts across KRT modalities by initial KRT modality. Number of shifts only reflects shifts across HD, PD and KTx. The maximum follow-up period was 10 years.

Iceland, and least frequent in Greece and Bosnia and Herzegovina (Supplementary data, Table S2).

Number of shifts by initial KRT modality

The number of shifts across modalities varied substantially by initial KRT modality (Table 2, Fig. 1, Supplementary data, Table S3). The majority of patients who initiated with HD or pre-emptive KTx experienced no shifts (75.5% and 88.0%, respectively), while most PD patients had one or more shifts across KRT modalities (67.9%). Differences in the number of shifts across age groups were most pronounced among patients who initiated with HD (Supplementary data, Table S1).

Patient trajectories

A Sankey plot summarizing the direction of shifts at each year of follow-up is shown in Fig. 2. Over the course of the study, the proportion of HD patients that died was greater than the proportion of HD patients that transitioned to KTx. This difference was most pronounced during the first year of follow-up, but remained evident throughout the duration of the study. In contrast, approximately equal proportions of PD patients transitioned to death as to KTx. However, on average, PD patients were also younger than HD patients. At the end of 10 years of follow-up, 69.5% of all patients died, 19.1% were living with a functioning graft and 8.5% were receiving dialysis (8.2% on HD; 0.3% on PD), while 1.7% of patients were lost to follow-up, and 1.2% experienced recovery of kidney function.

The 10 most frequent patient trajectories are summarized in Table 3. Overall, the most frequent trajectory, experienced by 53.4% of all patients, was KRT initiation with HD followed by death at mean 3.1 years. The next most frequent trajectories were initiation with HD followed by a transition to KTx at mean 2.9 years (10.2%), and initiation with and remaining on HD for 10 years of follow-up (5.6%). Of note, patients who underwent pre-emptive KTx and lived with a functioning graft for at least 10 years comprised the seventh most common trajectory (2.6%).

Patient trajectories by age, sex, PRD and country

Across all subgroups, the most frequent patient trajectory was HD followed by death, except for patients aged 20–44 years and those with ADPKD as PRD (Table 3), for which HD to KTx was the most frequent trajectory. Overall, younger patients initiated KRT with pre-emptive KTx or transitioned to KTx more frequently, whereas in patients ≥65 years, pre-emptive KTx did not make it to the top 10, occurring in <1% of cases. In all countries, HD followed by death was the most frequent trajectory, ranging from 36.5% and 38.2% in Iceland and Norway to 71.5% and 72.5% in Greece and Bosnia and Herzegovina (Fig. 3; Supplementary data, Table S4). The occurrence of HD to KTx ranged from 4.1% and 5.2% in Greece and Denmark to 14.0% and 14.8% in Spain and Iceland, and was the second most frequent trajectory in 9 out of 13 countries. In Denmark and Sweden, where more patients initiated with PD, the second most frequent trajectory was PD followed by death (8.9% and 10.9%). In Greece and Bosnia and Herzegovina, the second most frequent trajectory was remaining on HD for 10 years (10.1% and 13.6%, respectively), while this occurred only in 1.7% and 2.7% of KRT patients in Norway and Sweden.

Patient trajectories by initial KRT modality

The five most frequent patient trajectories by initial KRT modality are summarized in Supplementary data, Tables S5a–S5c Among HD patients, the most frequent trajectories were similar to those of all patients initiating KRT. Among patients who initiated with

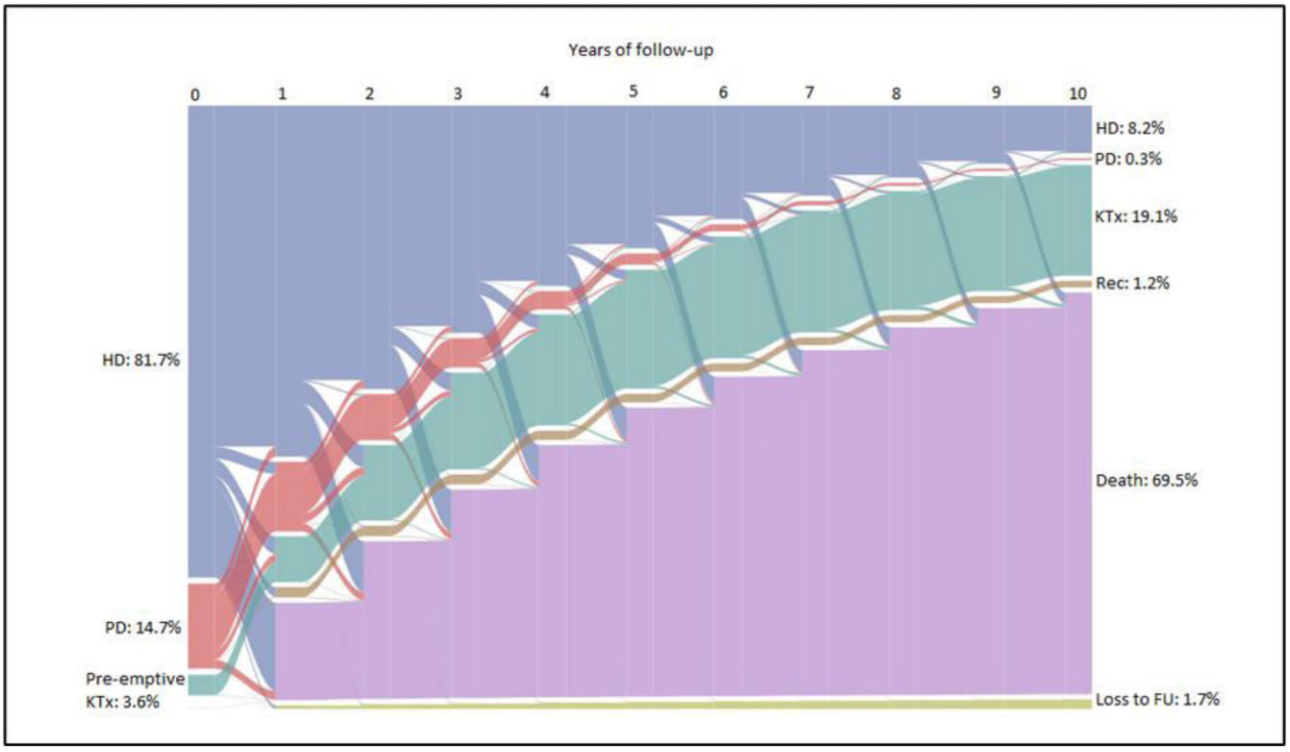


Figure 2: Patient trajectories at each year of follow-up. At the start of KRT, 81.7% of patients initiated with HD (blue), 14.7% initiated with PD (red) and 3.6% received a pre-emptive KTx (green). After 10 years of follow-up, 69.5% of patients died (purple), 19.1% were living with a functioning graft and 8.5% were receiving dialysis (8.2% on HD; 0.3% on PD), while 1.7% of patients were lost to follow-up and 1.2% of patients experienced recovery of kidney function. Rec: recovery of kidney function (>90 days); FU: follow-up.

PD, the most frequent trajectories were PD followed by death at mean 2.5 years (30.2%), and PD to KTx at mean 1.9 years (20.0%), after which patients lived with a functioning graft. Additionally, nearly a third of PD patients transitioned to HD, of whom most died thereafter (18.3%), but some went on to receive a kidney transplant (7.5%) or remained on HD (4.0%). Among patients who received a pre-emptive transplant, the majority lived with a functioning graft for 10 years (72.4%), while 13.2% died at mean 5.3 years and 3.5% transitioned to HD at mean 7.0 years.

Stratifying patient trajectories by initial KRT modality and subgroup revealed that for most subgroups, the most frequent trajectories were similar to the overall group (Supplementary data, Tables S5a–S5c). Surprisingly, among HD patients, 15.6% of those aged 20–44 years and 44.7% of those aged 45–64 years died on their initial modality. Trajectories for patients who initiated with HD were similar between countries, while those of patients initiating with PD or pre-emptive KTx showed greater between-country variance.

DISCUSSION

This study aimed to describe the number of shifts across KRT modalities and characterize the most frequent patient trajectories in the first 10 years following KRT initiation. Results showed that most patients remained on their initial KRT modality (69.6%), but younger patients and patients who initiated with PD experienced more shifts than others. Overall, the most frequent patient trajectories were HD followed by death (53.4%), HD to KTx (10.2%), remaining on HD the entire 10 years of follow-up (5.6%), PD followed by death (4.4%) and PD to KTx (2.9%). However, notable variations were observed between European countries.

Most frequent patient trajectories

The three most frequent patient trajectories began with HD, which is the most common initial KRT modality worldwide [5, 7, 8]. Most patients who initiated with HD died (65.4%) at mean 3.1 years, and even among younger HD patients <65 years of age, mortality during HD treatment was considerable. The underlying reasons for the high mortality in younger patients initiating with HD are still not well understood, but potential contributing factors may include the presence of comorbidities and the type of vascular access used at HD initiation. Comorbidities are associated with a higher risk of death in KRT patients [7], and a lower likelihood of transitioning across KRT modalities [13]. In 2014, 9.5% of patients aged 20–44 years and 28.8% of patients aged 45–64 years starting KRT in Europe had multiple comorbidities [14]. Likewise, central venous catheters (CVCs) are associated with higher risk of infections, hospitalizations and death compared with an arteriovenous fistula or graft [15]. In Europe, CVC-use at HD initiation ranged between 58% and 88% in 2005–23 [16–18], though its prevalence is likely lower in younger compared with older dialysis patients [16]. Unfortunately, data on comorbidities and vascular access type were not available for the present study, but should be included in future research investigating mortality in young HD patients.

The second and third most frequent trajectory consisted of HD patients who received a kidney transplant and kept their graft for the remainder of follow-up (12.5% of HD patients), and patients who initiated with and remained on HD for 10 years (6.8%). Considering the latter group of patients were "healthy enough" to survive 10 years on HD, they may also have been "healthy enough" to undergo KTx. However, as we did not have data on the kidney transplant waiting list, we were unable to determine which

Table 3: Top 10 most frequent patient trajectories by age, sex and PRD.

Subgroups	Patient trajectory	N	Col. %	Abs. duration on each modality, mean years (SD)
Total	HD > Death	154 540	53.4	3.1 (2.6)
	HD > KTx	29 643	10.2	2.9 (2.1) > 7.1 (2.1)
	HD	16 103	5.6	10 (0)
	PD > Death	12 828	4.4	2.5 (2)
	PD > KTx	8523	2.9	1.9 (1.5) > 8.1 (1.5)
	PD > HD > Death	7774	2.7	1.9 (1.8) > 2.6 (2.3)
	KTx	7505	2.6	10 (0)
	HD > KTx > Death	7372	2.5	2.6 (1.7) > 3.7 (2.5)
	HD > PD > Death	3413	1.2	0.8 (1.5) > 1.9 (1.9)
	PD > HD > KTx	3205	1.1	1.6 (1.4) > 2.0 (1.7) > 6.4 (2.1)
Age at KRT initiation				
20–44 years	HD > KTx	10 743	31.4	2.8 (2.2) > 7.2 (2.2)
	HD > Death	3565	10.4	3.5 (2.8)
	PD > KTx	3342	9.8	1.8 (1.5) > 8.2 (1.5)
	KTx	3146	9.2	10 (0)
	HD	1797	5.3	10 (0)
	PD > HD > KTx	1287	3.8	1.6 (1.4) > 1.9 (1.7) > 6.5 (2.1)
	HD > KTx > HD	1045	3.1	2.7 (1.9) > 4.1 (2.7) > 3.2 (2.4)
	HD > PD > KTx	767	2.2	0.5 (0.9) > 1.8 (1.5) > 7.7 (1.7)
	HD > KTx > Death	681	2.0	2.6 (1.9) > 3.6 (2.6)
	HD > Lost to FU	542	1.6	1.9 (2.2)
45–64 years	HD > Death	30 364	34.3	3.5 (2.8)
	HD > KTx	16 046	18.1	3.0 (2.1) > 7.0 (2.1)
	HD	6408	7.2	10 (0)
	PD > KTx	4457	5.0	2.0 (1.5) > 8.0 (1.5)
	HD > KTx > Death	4100	4.6	2.8 (1.8) > 3.7 (2.5)
	KTx	3719	4.2	10 (0)
	PD > Death	2533	2.9	2.6 (2.1)
	PD > HD > Death	2094	2.4	2.1 (1.8) > 2.6 (2.3)
	PD > HD > KTx	1685	1.9	1.7 (1.5) > 2.1 (1.7) > 6.2 (2.1)
	HD > KTx > HD	1513	1.7	3.0 (1.9) > 3.7 (2.7) > 3.3 (2.4)
65–74 years	HD > Death	47 227	62.8	3.4 (2.7)
	HD	5223	6.9	10 (0)
	PD > Death	3765	5.0	2.7 (2.1)
	HD > KTx	2734	3.6	2.5 (1.7) > 7.5 (1.7)
	PD > HD > Death	2641	3.5	2.2 (1.9) > 2.6 (2.4)
	HD > KTx > Death	2302	3.1	2.3 (1.5) > 3.8 (2.6)
	HD > PD > Death	1038	1.4	0.9 (1.4) > 2.0 (1.9)
	HD > Rec	816	1.1	0.8 (1.2)
	HD > Lost to FU	769	1.0	2.4 (2.6)
	PD > KTx	698	0.9	1.9 (1.3) > 8.1 (1.3)
75+ years	HD > Death	73 384	80.1	2.8 (2.5)
	PD > Death	6202	6.8	2.3 (1.9)
	HD	2675	2.9	10 (0)
	PD > HD > Death	2658	2.9	1.6 (1.6) > 2.5 (2.2)
	HD > PD > Death	1275	1.4	0.6 (1.2) > 1.7 (1.8)
	HD > Rec	936	1.0	0.7 (1.3)
	HD > Lost to FU	704	0.8	1.9 (2.3)
	HD > Rec > Death	640	0.7	0.7 (1.0) > 2.8 (2.2)
	HD > PD > HD > Death	498	0.5	0.4 (0.6) > 1.2 (1.4) > 2.3 (2.3)
	HD > Rec > HD > Death	344	0.4	0.6 (0.9) > 1.7 (1.5) > 2 (1.8)
Sex				
Women	HD > Death	57 088	53.2	3.2 (2.7)
	HD > KTx	10 462	9.7	2.9 (2.2) > 7.1 (2.2)
	HD	6798	6.3	10 (0)
	PD > Death	4649	4.3	2.5 (2.1)
	PD > KTx	3493	3.3	2.0 (1.6) > 8.0 (1.6)
	KTx	3058	2.8	10 (0)
	PD > HD > Death	2704	2.5	1.9 (1.9) > 2.6 (2.4)
	HD > KTx > Death	2246	2.1	2.6 (1.8) > 3.7 (2.6)
	HD > PD > Death	1353	1.3	1.0 (1.7) > 1.9 (2.0)
	PD > HD > KTx	1259	1.2	1.7 (1.5) > 2.2 (1.8) > 6.2 (2.2)

Table 3: Continued

Subgroups	Patient trajectory	N	Col. %	Abs. duration on each modality, mean years (SD)
Men	HD > Death	97 452	53.5	3.1 (2.6)
	HD > KTx	19 181	10.5	2.8 (2.1) > 7.2 (2.1)
	HD	9305	5.1	10 (0)
	PD > Death	8179	4.5	2.5 (2.0)
	HD > KTx > Death	5126	2.8	2.6 (1.7) > 3.7 (2.5)
	PD > HD > KTx	5070	2.8	2.0 (1.7) > 2.6 (2.3)
	PD > KTx	5030	2.8	1.8 (1.4) > 8.2 (1.4)
	KTx	4447	2.4	10 (0)
	HD > PD > Death	2060	1.1	0.7 (1.3) > 1.9 (1.8)
	PD > HD > KTx	1946	1.1	1.6 (1.4) > 1.9 (1.6) > 6.5 (2.0)
PRD				
Diabetes	HD > Death	42 039	61.8	3.4 (2.6)
	HD > KTx	4074	6.0	3.0 (2.0) > 7.1 (2.0)
	PD > Death	3549	5.2	2.5 (1.9)
	HD	3500	5.1	10 (0)
	PD > HD > Death	2333	3.4	1.9 (1.7) > 2.5 (2.2)
	HD > KTx > Death	1968	2.9	2.7 (1.7) > 3.7 (2.5)
	PD > KTx	1090	1.6	1.8 (1.3) > 8.2 (1.3)
	HD > PD > Death	1022	1.5	0.9 (1.5) > 1.9 (1.7)
	KTx	856	1.3	10 (0)
	HD > Lost to FU	650	1.0	2.4 (2.5)
HTN/RVD	HD > Death	33 836	62.4	3.2 (2.6)
	HD > KTx	3427	6.3	3.1 (2.1) > 6.9 (2.1)
	PD > Death	3326	6.1	2.5 (2.0)
	HD	2908	5.4	10 (0)
	PD > HD > Death	1706	3.1	2.0 (1.8) > 2.6 (2.3)
	HD > KTx > Death	1239	2.3	2.5 (1.6) > 3.7 (2.5)
	PD > KTx	752	1.4	2.1 (1.5) > 7.9 (1.5)
	HD > PD > Death	716	1.3	0.7 (1.3) > 1.9 (1.8)
	HD > Lost to FU	520	1.1	2.1 (2.4)
	HD > KTx > HD	439	0.8	3.0 (1.8) > 3.7 (2.5) > 3.3 (2.3)
Glomerulonephritis	HD > Death	10 418	31.3	3.6 (2.8)
	HD > KTx	6527	19.6	2.7 (2.1) > 7.3 (2.1)
	PD > KTx	2366	7.1	1.8 (1.5) > 8.2 (1.5)
	HD	2008	6.0	10 (0)
	KTx	1617	4.9	10 (0)
	HD > KTx > Death	1079	3.2	2.6 (1.8) > 3.9 (2.6)
	PD > HD > KTx	862	2.6	1.5 (1.4) > 1.9 (1.7) > 6.5 (2.1)
	PD > Death	844	2.5	2.9 (2.2)
	HD > KTx > HD	754	2.3	2.6 (1.8) > 3.9 (2.8) > 3.5 (2.5)
	PD > HD > Death	711	2.1	2.2 (1.8) > 2.9 (2.4)
ADPKD	HD > KTx	5263	29.6	2.5 (2.0) > 7.5 (2.0)
	HD > Death	3764	21.2	4.3 (2.8)
	KTx	1423	8.0	10 (0)
	PD > KTx	1292	7.3	1.9 (1.4) > 8.1 (1.4)
	HD	1263	7.1	10 (0)
	HD > KTx > Death	786	4.4	2.4 (1.7) > 3.9 (2.6)
	PD > HD > KTx	529	3.0	1.7 (1.5) > 1.9 (1.6) > 6.4 (2)
	PD > HD > Death	364	2.0	2.3 (1.9) > 2.8 (2.5)
	PD > Death	337	1.9	3.3 (2.3)
	HD > KTx > HD	330	1.9	2.7 (2.0) > 4.0 (2.8) > 3.4 (2.6)
Miscellaneous	HD > Death	33 679	52.5	2.8 (2.6)
	HD > KTx	6516	10.2	3.0 (2.2) > 7.0 (2.2)
	HD	3653	5.7	10 (0)
	PD > Death	2188	3.4	2.4 (2.1)
	KTx	2076	3.2	10 (0)
	PD > KTx	1879	2.9	2.0 (1.5) > 8.0 (1.5)
	HD > Rec	1427	2.2	0.7 (1.1)
	HD > KTx > Death	1371	2.1	2.7 (1.7) > 3.6 (2.6)
	PD > HD > Death	1264	2.0	1.9 (1.9) > 2.6 (2.3)
	HD > PD > Death	756	1.2	0.8 (1.4) > 1.9 (1.9)

Table 3: Continued

Subgroups	Patient trajectory	N	Col. %	Abs. duration on each modality, mean years (SD)
Unknown/missing	HD > Death	30 804	59.5	2.8 (2.6)
	HD > KTx	3836	7.4	3.1 (2.2) > 6.9 (2.2)
	HD	2771	5.4	10 (0)
	PD > Death	2584	5.0	2.3 (2)
	PD > HD > Death	1396	2.7	1.9 (1.7) > 2.5 (2.3)
	PD > KTx	1144	2.2	2.1 (1.6) > 7.9 (1.6)
	KTx	1128	2.2	10 (0)
	HD > KTx > Death	929	1.8	2.6 (1.7) > 3.7 (2.5)
	HD > Lost to FU	743	1.4	1.8 (2.2)
	HD > PD > Death	600	1.2	0.8 (1.5) > 1.8 (1.9)

The maximum follow-up period was 10 years. Totals may not add up due to rounding.
Abs: absolute; SD: standard deviation; Rec: recovery of kidney function (>90 days); FU: follow-up; Col: column.

patients had been waitlisted and which were deemed ineligible for KTx, for example, due to recurrent disease, cardiovascular disease or other contraindications [19–21]. While some patients may face delays due to challenges in matching donor and recipient blood type or antibodies, waiting times are unlikely to extend to 10 years. A key finding among HD patients was the relatively high prevalence of those <65 years of age who died on their initial KRT modality or those who remained on HD for 10 years. Ideally, these patients would have received a donor kidney during that time, but did not, due to transplant ineligibility, organ shortages or other barriers. These results highlight the need for patients with kidney failure to create individualized dialysis life plans with initial and potentially subsequent modalities planned out in case a transition towards KTx is not feasible. This would contribute to a more integrated approach to KRT care [18].

The fourth, fifth and sixth most common trajectories began with PD, with the most frequent being PD followed by death (30.2% of PD patients). Death following initiation with PD occurred less frequently compared with HD patients (65.4% of HD patients), likely because PD patients were, on average, younger than those on HD. Additionally, nearly a third of patients who initiated KRT with PD eventually transitioned to HD, which is rather indicative of treatment with PD, as long-term PD use can be hampered by infections, mechanical complications or the loss of peritoneal membrane function [12, 22–25]. Notably, patients who initiated KRT with PD experienced more modality shifts than those who initiated with HD, regardless of age. Lastly, 20.0% of PD patients transitioned to KTx and lived with a functioning graft for the remainder of the study. This proportion was higher than that of HD patients (12.5%), likely reflecting younger age. Some studies have named PD a "bridging therapy" to more definitive KRT options [26], such as KTx, due to benefits in preserving residual kidney function and increased patient survival [26, 27]. These advantages are most apparent in the first 12–15 months of PD treatment [28, 29], making PD a desirable option for patients awaiting KTx. Our findings related to the discontinuation of PD mirror previously conducted research where most patients ceased PD treatment within 2–3 years due to death, or a transition to HD or KTx [12, 30–32].

Finally, the seventh most common trajectory was pre-emptive KTx, which was the most stable starting modality, as 72.4% of patients lived with a functioning graft for at least 10 years. On average, a kidney transplant can last between 8–30 years [33–35], indicating a substantial portion of graft failures will have occurred beyond the timeframe of this study. Overall, pre-emptive KTx was less common (2.6%) than KTx following HD (10.2%) or PD (2.9%), but other studies have shown an increasing trend towards pre-emptive KTx [5, 7, 10, 36]. Our data showed differences in patient trajectories involving KTx across age and PRD groups, but not between women and men. The underlying factors for differences in accessing KTx are often related to the presence of comorbidities, which are more common in older patients [37]. Incentives towards increasing living-donor KTx among older patients may also help increase the rate of pre-emptive KTx among older patients [36, 38].

Differences across European countries

The most frequent patient trajectories differed between European countries, which is likely caused by differences in the availability of KRT treatments. Some European countries have a lower KTx rate compared with others [5, 39], contributing to fewer transitions from dialysis to KTx and more patients remaining on HD for 10 years. This is also reflected in the low number of shifts across KRT modalities observed in Greece and Bosnia and Herzegovina. Differences in the availability and accessibility of KRT treatments are a function of local resources, reimbursement policies, infrastructure, and patient and nephrologist preference [3]. In Sweden and the UK, PD has been promoted as the preferred treatment option for younger and healthier patients with preserved residual kidney function and without significant comorbidity [40, 41], while in Denmark, some hospitals have implemented programs to stimulate PD among frail, elderly and physically dependent patients [42]. Our results show that Denmark, Sweden and the UK, in addition to Finland and Iceland, all have a relatively large proportion of patients initiating with PD (24%–31%) and also appear to have a higher utilization of PD compared with other countries. This is also reflected in the higher number of shifts across KRT modalities observed in these countries. Additional examples of health policies may include programs promoting living or deceased donor KTx, such as those in the Netherlands [43] or Spain [44], or practices influencing access to the kidney transplant waiting list [36]. In Norway and in the Netherlands, pre-emptive KTx (and living with a functioning graft for 10 years) was the third most frequent trajectory, while in Finland, Greece, and Bosnia and Herzegovina, pre-emptive KTx did not make the top 10 of most frequent trajectories. Future studies could further explore differences in patient trajectories between countries, for instance, by focusing on patients remaining on HD for 10 years, which varied between 1.7% and 13.6% among participating countries. Such investigations may help refine current practices and support more individualized approaches to patient care.

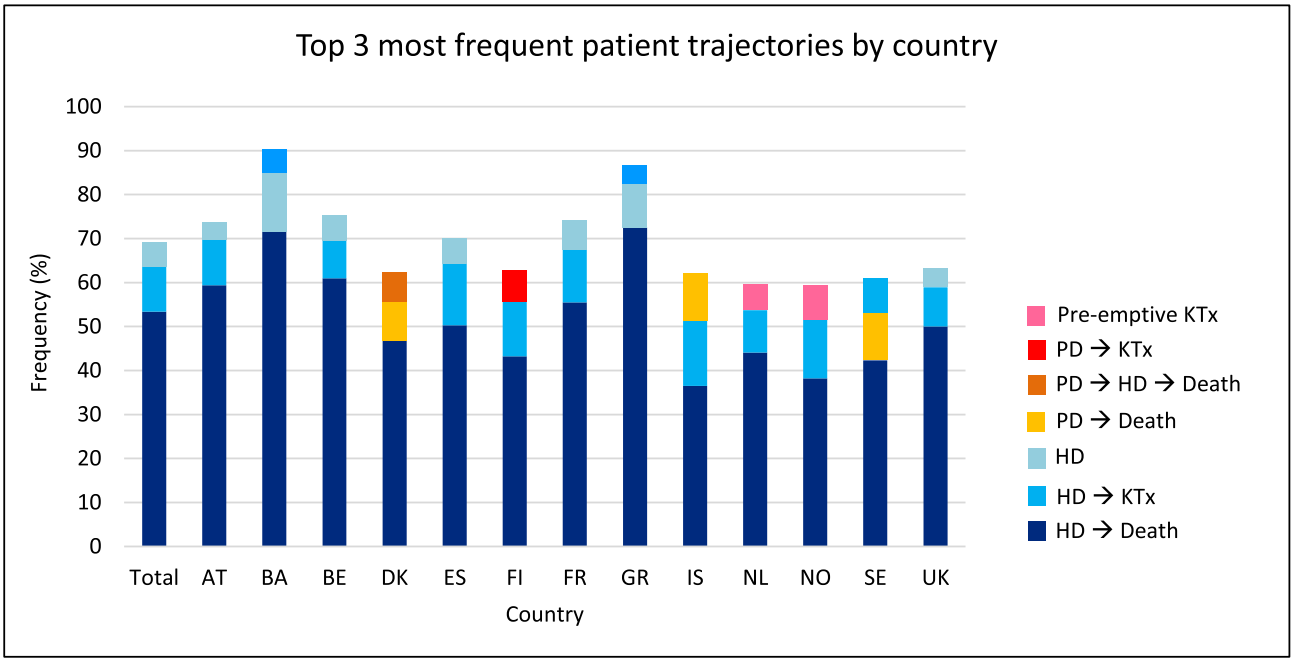


Figure 3: Top three most frequent patient trajectories by country. Each bar reflects the three most frequent patient trajectories per country. The total height of each bar reflects the proportion of patients per country who had a patient trajectories featured in the three most common patient trajectories. AT: Austria; BA: Bosnia and Herzegovina; BE: Belgium; DK: Denmark; ES: Spain; FI: Finland; FR: France; GR: Greece; IS: Iceland; NL: Netherlands; NO: Norway; SE: Sweden: UK: the United Kingdom.

Strengths and limitations

Strengths of this study include the large sample size and the availability of complete and longitudinal data for 13 European countries. Patient trajectories are best captured by renal registries that collect data on a patient's entire KRT journey, including the time spent on dialysis. This study also has several limitations. Not all European countries are covered by the ERA Registry, and therefore, results might not be representative for all of Europe. We included and summarized the results of patients who initiated KRT between 2004 and 2013 to enable a complete 10-year follow-up period, but this may not reflect findings of patients who initiated KRT more recently. Additionally, while a 10-year follow-up is long in duration, it may not cover the entire lifespan of a patient with kidney failure, and therefore may not capture all potential transitions across modalities. Finally, we had no information regarding the reasons for transitioning between KRT modalities, nor did we have data related to comorbidities or whether patients had been admitted to the kidney transplant waiting list. These important factors would have helped us better understand (differences in) treatment trajectories of patients with kidney failure, and should be included in future research.

CONCLUSIONS

More than two-thirds of patients remained on their initial KRT modality until death or the end of 10-years follow-up, but younger patients and patients who initiated with PD had more shifts across KRT modalities than others. Overall, the most frequent patient trajectories were HD followed by death, HD to KTx, remaining on HD for 10 years, PD followed by death and PD to KTx. The number and direction of shifts across KRT modalities varied by age, PRD, country and initial KRT modality, but not by sex. Future research should further investigate trajectories of patient subgroups that stood out in this study, including young HD patients who died on their initial KRT modality and those who remained on HD for 10 years without undergoing KTx.

SUPPLEMENTARY DATA

Supplementary data are available at *Nephrology Dialysis Transplantation* online.

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AUTHORS' CONTRIBUTIONS

Conceptualization: B.A.B., A.K., K.J.J., V.S.S. and P.M.F.; methodology: B.A.B., A.K., K.J.J., V.S.S. and P.M.F.; formal analysis: B.A.B. and A.K.; writing—original draft: B.A.B., A.K., K.J.J., V.S.S. and P.M.F.; writing—review and editing: A.L., S.A.B., A.Å., M.A.G.J.D., S.A.G.-M., M.A., O.S.I., A.M.-T., K.H., L.B., M.C., O.L.R.A., P.F., V.K., M.O.V., S.M., B.P., L.H. and A.O.; all authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data underlying this article cannot be shared with any third party because the national and renal registries that provided data to the European Renal Association (ERA) Registry remain the owners of the data.

CONFLICT OF INTEREST STATEMENT

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