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Original Article

Simulation model of renal replacement therapy: predicting future demand in England

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Abstract

Background. The demand for renal replacement therapy (RRT) in England has risen steadily, although from a lower base than many other developed countries. Predicting the future demand for RRT and the impact of factors such as the acceptance rate, transplant supply and patient survival, is required in order to inform the planning of such services.

Methods. A discrete event simulation model estimates the future demand for RRT in England in 2010 for a range of scenarios. The model uses current prevalence and current and projected future acceptance rates, survival rates and the transitions between modalities to predict future patient numbers. National population and mortality data, published literature and data from the UK Renal Registry and UK Transplant, are used to estimate unmet need for RRT, the impact of changing demography and incidence of Type 2 diabetes, patient haemodialysis (HD) survival and transplant supply.

Results. By 2010 the predicted prevalence will have increased from about 30 000 in 2000 to between 42 and 51 000 (900–1000 p.m.p.), an average annual growth of 4.5–6%. Changing transplant supply has a small effect on overall numbers but changes the proportion of patients with functioning graft by up to 8%. Even with an optimistic increase in transplant supply (11% p.a. for 5 years), numbers on HD will continue to rise substantially, especially in the elderly. The factors most influencing future patient numbers are the acceptance rate and dialysis survival.

Conclusion. This model predicts a substantial growth in the RRT population to 2010 to a rate approaching 1000 p.m.p., particularly in the elderly and those on HD, with a steady state not being reached for at least 25 years.

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Introduction

There has been a significant rise in the number of patients treated with renal replacement therapy (RRT) in England over the last decade, from an estimated 396 p.m.p. in 1993 to 523 p.m.p. in 1998 [1]. This growth has been due partly to liberalization of referral and acceptance, especially in the elderly and those with co-morbid illness, with the acceptance rate rising from 65 p.m.p. in 1992 to 90 p.m.p. by 1998 [1]. More recent acceptance rate estimates, extrapolated from the partial coverage of the UK Renal Registry, suggest that the rate of increase is levelling off but this will need to be checked as more complete national data become available in future. It is likely, however, that as this rate is still below those of many similar developed countries, there is a persistent unmet need for RRT in the UK as a result of an under-provision of renal services. The impact of demographic change, particularly the ageing of the ethnic minority population who have higher rates of renal disease [2], and the increase in Type 2 diabetes, may have contributed to the rise, and will continue to affect demand. The pattern of RRT modes [1] has changed due to falling cadaver kidney donor numbers [3], with consequent growth in dialysis, particularly hospital haemodialysis (HD) in satellite units. The potential for increased patient survival with the introduction of newer service standards [4] could have significant consequences for RRT numbers in the future. The impact of these factors on future demand for RRT require evaluation to enable health service providers to plan services.

This paper describes the use of a simulation model to estimate such demand. It is an update of an earlier, less powerful model [5] that used parameters from the late

1980s and early 1990s, and predicted demand over the subsequent 10 years. The model predicted a range of results, depending on the assumptions. Those using the highest acceptance rate (87 p.m.p.) and improved survival were consistent with the estimates of stock in England in 2000 [5]. The current model is a user-friendly Windows-based model, which is much faster than the previous model and incorporates more risk factors, live transplants and provides for the analysis transfers between the different modes of dialysis. It incorporates updated national information on transitions, survival, transplant supply and acceptance rates. It is designed to assess the impact on predicted patient numbers of a rising acceptance rate, potential increases in diabetic end-stage renal failure (ESRF), changing cadaveric and live donor organ supply, the provision and allocation of different treatments, and increasing patient survival.

Subjects and methods

The simulation model

The discrete event simulation, using the patient-oriented simulation technique (POST) software [6] describes the changing modalities of individual simulated patients in year 2000 for up to 30 years into the future. The simulation describes the progress of the prevalent patients on each modality in the year 2000 based on sampled survival times, until the end of the simulation, or death. New incident patients are accepted on to the programme each year and after allocation to their initial modality are treated in the same way as prevalent patients. Live and cadaver kidneys are generated independently of patient numbers and are allocated to patients as they arrive. The simulation advances in time order with the progress of patients influenced by their risk group and suitability for transplantation. Figure 1 shows the flow of patients through the model.

The simulation needs data by risk group on current and future acceptance rates, the prevalence in year 2000 by modality, patient suitability for transplantation, priorities for transplantation and patient and treatment survival. It also needs to know the current transplant rate and potential future changes to it.

In order to take account of age, patients over the age of 16 were divided into 10-year age groups up to age 75, with those older grouped as 75+. Co-morbidity is also important but individual patient co-morbidity data were unavailable and so the presence of diabetes as a cause of ESRF was used as a proxy. A risk group was therefore defined as age group broken down by the presence or absence of diabetes. The parameters used in the model are posted on our website (http://www.som.soton.ac.uk/research/cbcs/hcru/pubs.htm).

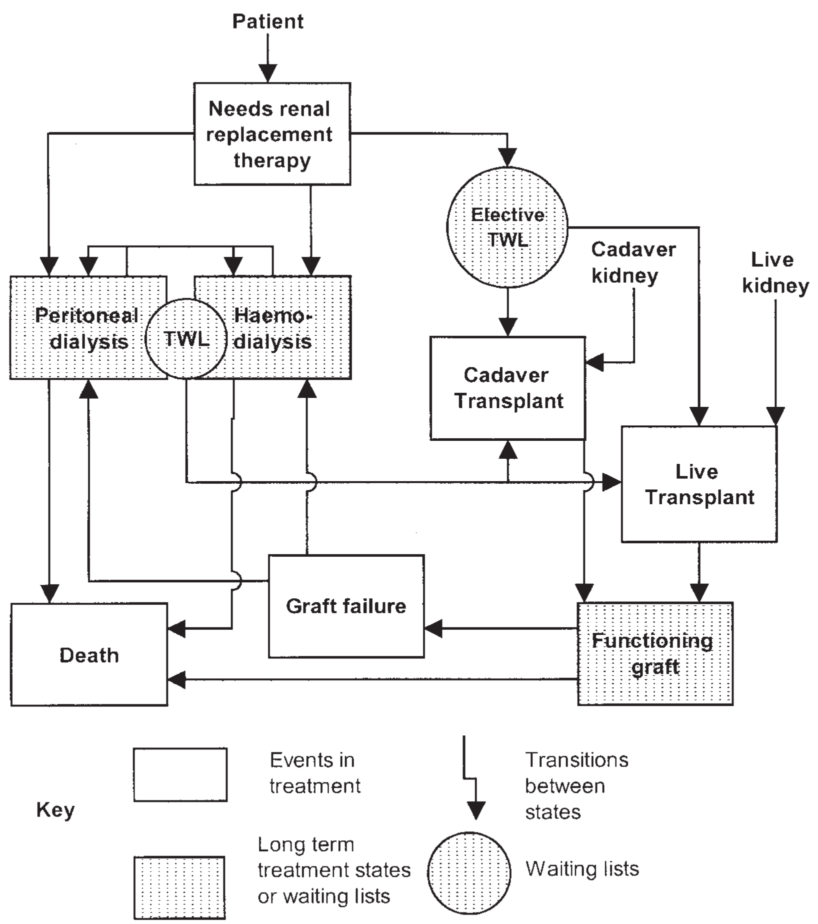

Fig. 1. Schematic diagram of flows of patients through the model (TWL = Transplant Waiting List).

Estimated acceptances in year 2000

The starting acceptance patterns were based on the incident data on those patients accepted for RRT in the 25 (40%) centres in England (out of a total number of 63) that were contributing to the UK Renal Registry (UKRR) between 1997 and 2000. To estimate the current acceptance rate in 2000 we used two methods to 'scale up' the data to national levels. The first (Renal Registry based 'RR') used the estimated catchment populations of the participating units and increased the 2000 acceptances in proportion to the 2000 national population, giving an acceptance rate of 94 p.m.p. with 49% aged over 65 and 17% with diabetic ESRF. The second (Renal Survey based 'RS'), which we believed to be more accurate, used the 1998 National Renal Survey [1], which had 100% response rates from all renal units. We obtained the survey data on number of acceptances, the proportions aged over 65 and the proportions with diabetic ESRF for those units contributing to the UKRR acceptance data in 2000. We then compared the data with figures for those units not contributing to the UKRR. This showed that the proportion of patients aged over 65 was higher for the UKRR than the non-UKRR units at 46 and 36%, respectively. Taking this into account gave a higher starting acceptance rate of 104 p.m.p., with 42% aged over 65 and 17% with diabetic ESRF. We used the RS figures for most estimates but investigated use of RR figures in sensitivity analysis.

Estimated acceptances in year 2010

In estimating the numbers of acceptances by risk group in England for year 2010 we assumed that there would be a linear increase or decrease in the acceptance rate by risk group from year 2000 to year 2010. The calculations were done in three parts: we first derived the estimated national population in 2010 for the ethnic minority (i.e. Indo-Asian and African-Caribbean) and non-ethnic minority groups separately, as there is a different age profile and risk of RRT in the different ethnic groups [2]. We then determined an acceptance rate for each age and ethnic minority group, in 2010 using rates from other countries as estimates of meeting unmet need in England, and giving a proportionately higher rate for ethnic minority groups [2]. Finally, we then multiplied the rates by the population, subdivided by the ethnic and non-ethnic populations and then totalled the acceptances by age group. The acceptances by age group were then subdivided into a diabetic and non-diabetic group, using the proportion of new patients listed as diabetic or non-diabetic by age and ethnicity from UK Renal Registry.

To derive the population projections, we used the Office for National Statistics (ONS) Labour Force Survey [7], which gives an estimate of the UK population by age and ethnic group. We predicted the two populations using 'all cause mortality' data from ONS for 1999. Excluding migrants, we estimated the overall population of England at 2010 to be 50.1 million, compared with an ONS estimated population in 2011 of 51 million [8].

We took account of unmet need for RRT in England by assuming that the age sex acceptance rates in England in 2010 would have increased to the higher rates found in other UK countries, such as Scotland and Wales in 1998, and by applying these higher rates to the estimated 2010 English population. Due to the lower ethnic minority population in Scotland and Wales we did this for the non-ethnic minority population and adjusted the ethnic minority rate in England as above.

Starting stock and the initial mode of therapy by age group and diabetic kidney disease status

A 'timeline' of treatment modes for each patient from the UKRR, including their cause of renal failure, starting mode, changes of mode and their duration were obtained. These were used to ascertain the initial mode of RRT by age and diabetes ESRF for the model population. Age- and diabetes-specific RRT prevalence data from the proportion of units in England in the UKRR at end of 2000 were used to ascertain the characteristics of the starting stock of prevalent patients. Again, two different methods were used to scale up the numbers to represent the whole of England, denoted RR and RS, as for acceptances. The RS starting stock is 33 307 (660 p.m.p.) with 24% over 65 years. The RR starting stock is 29 312 (582 p.m.p.) with 28% over 65 years. Table 1 shows the breakdown of stock by age, diabetic ESRD and mode of treatment.

Survival

Data were obtained from UKRR on the characteristics and subsequent modes of treatment and date of death on all new patients starting RRT, in the 35 UK centres (out of a total number of 68) participating in UKRR, in the period 1997–2001. The data were used to calculate dialysis patient and mode survival from the start of treatment by age group and diabetic status. Mode survival was derived from the time a patient spent on HD before transferring to peritoneal dialysis (PD), or vice versa; those censored were transplants, deaths and transfers out of a UKRR centre. For patient survival by mode, the event was death and those censored were switches to a different mode, or transfers out of a UKRR centre. Mode and patient survival were calculated using Kaplan–Meier survival curves. Transplant and patient survival data by live grafts, and cadaver first and re-grafts by age group were provided by UK Transplant (UKT). Mode survival and patient survival was fitted by two exponentials, one for the early months of survival and one for the later ones. Details of the methods and exemplar parameters are shown on the website (http://www.som.soton.ac.uk/research/cbcs/hcru/pubs.htm).

Transplant supply and organ allocation

UKT provided data on the numbers of live and cadaver transplants performed in the UK in 2000 by age group. We then used estimates from the UK Transplant Business Case, which detailed the steps being taken to increase the number of organs available over the 5-year period 2000–2005 [3], to test the effect of three scenarios of the change in transplant supply to 2005. 'Low transplant' assumed no change in the number of transplants (22 p.m.p. cadaver, 5 p.m.p. live), 'High transplant' assumed all of the UKT target average annual increase of 11% over 5 years is achieved (30 p.m.p. cadaver, 13 p.m.p. live), 'Pragmatic' assumed only 90% of the live and 65% of the cadaver target increase would be achieved in this 5-year period.

Table 1. Starting stock in 2000 of patients for RS and RR for England based scenarios by mode and diabetic ESRD

Existing mode	Age group							
	16–24	25–34	35–44	45–54	55–64	65–74	75+	Total
National Renal Survey based (RS) starting stock ($n = 33\,307$)								
Diabetic								
HD	39	118	183	240	330	348	281	1540
PD	29	85	121	169	235	182	101	923
TX	36	174	266	246	238	50	0	1011
Non-diabetic								
HD	256	771	1192	1564	2147	2269	1829	10028
PD	140	418	596	833	1158	896	498	4538
TX	555	2302	3620	3630	3631	1387	143	15267
UK Renal Registry based (RR) starting stock ($n = 29\,312$)								
Diabetic								
HD	33	99	153	200	275	358	289	1406
PD	24	71	101	141	196	187	104	824
TX	30	145	222	205	198	51	0	852
Non-diabetic								
HD	213	643	994	1304	1789	2333	1880	9155
PD	117	348	497	694	965	921	512	4054
TX	462	1918	3017	3025	3026	1426	147	13021

HD = haemodialysis; PD = peritoneal dialysis; TX = transplant.

Some prevalent patients had to be put on the transplant waiting list at the start, all patients in the simulation had to be ‘labelled’ as being suitable for transplantation or not and those on the transplant waiting list were given one of three priority classifications. The allocations were based on data provided by UKT by age and diabetes status (personal communication Rachel Johnson 2002), including:

- Those on the active transplant waiting list at 01.01.1999.
- The proportion who joined the transplant waiting list within the first year of RRT.
- The chances of listing for a transplant following previous transplantation.
- A risk score derived from UKT, which predicted the time to transplant for 3957 new patients on the transplant waiting list.

Modelling uncertainty

The simulation was run with data for the whole of England for up to 30 years with five replications.

The confidence limits of the estimated numbers on treatment for England in 10 years’ time, given the expected variability in the acceptance and transplant rate were within plus or minus 2.5% of the total for each mode of treatment (HD, PD and transplanted patients) and within plus or minus 1% for the predicted total number on treatment.

Scenarios

In the Base scenario we assumed that 2010 age and ethnic acceptance rates were based on year 2000 for Wales, taking account of demographic population changes in England. It used RS as baseline incidence and prevalence rates for year 2000 and assumed a pragmatic increase in transplants.

The other scenarios analysed for this paper are:

(i) Low acceptance rate (AR). 2010 age and ethnic acceptance rates remain the same as estimated for 2000 for England (RS), but take account of population changes. Uses RS estimate as baseline acceptance and stock rates and has pragmatic increase in transplants.

(ii) Medium acceptance rate (AR). 2010 age and ethnic acceptance rates based on year 2000 for Scotland, taking account of population changes in England. Uses RS as baseline and has pragmatic increase in transplants.

(iii) 10% > Diabetes. Uses Base scenario but the incidence of diabetic ERF in the population increases by a ‘conservative’ 10% in all ages, based on analysis conducted by the UK Office for National Statistics (ONS) on trends in diabetes prevalence using the General Practice Research Database [9], which showed increases in prevalence of nearly 20% from 1994 to 1998. Uses RS as baseline and has pragmatic increase in transplants.

(iv) 50% > Diabetes. Uses the Base scenario but acceptance of diabetics increases by 50% in each age group older than 45, to provide a high estimate of the impact of the increasing incidence of Type 2 diabetes. Uses RS as baseline and has pragmatic increase in transplants.

(v) Low transplant. The same as the Base scenario except that there is no increase in transplants.

(vi) High transplant. Same as the Base scenario except that there is maximum increase in transplants.

(vii) High HD patient survival. Same as the Base scenario except that HD survival had been increased by the difference between the UK and other European centres seen in the IDOPPS study [10]. This is illustrative only; the IDOPPS result may be due to selection effect as there is a much higher proportion of RRT patients on HD in the European centres in the study than in the UK [11].

(viii) Choice. Same as the Base scenario except that there was a different balance between HD and PD by taking account of patient choice [12] with a wider availability of HD. In this scenario we increased the proportion of incident patients over 55 starting HD by 10% in absolute terms and reduced it by the same amount for PD.

Table 2. Estimated number of acceptances in England in 2000 (RS and RR) and predicted 2010 acceptances for each scenario by age and diabetic ESRD (DM)

Age	2000 'RS' acceptances		2000 'RR' acceptances		'Base AR'		'Low AR'		'Medium AR'		'10% > DM'		'50% > DM'	
	DM	Non-DM	DM	Non-DM	DM	Non-DM	DM	Non-DM	DM	Non-DM	DM	Non-DM	DM	Non-DM
16–34	64	599	51	481	66	684	48	569	49	467	73	684	66	684
35–44	138	416	111	334	188	572	115	348	129	392	207	572	188	572
45–54	130	467	105	375	197	695	123	433	151	533	217	695	296	695
55–64	259	955	208	766	347	1238	260	926	293	1045	382	1238	521	1238
65–74	251	1143	261	1192	413	1775	355	1523	378	1623	454	1775	620	1775
75+	70	760	73	793	183	1754	105	968	115	1111	201	1754	274	1754

(ix) RR. The same as the Base scenario except that it uses the RR estimates of acceptance and stock rates as the baseline, to test the uncertainty in the starting position as national coverage in England has not yet been achieved by the UKRR.

Table 2 shows the age and diabetic ESRD distributions for the scenarios, which vary the acceptance rate.

Results

Table 3 summarizes the estimates of future acceptance and prevalence with age and modality specifics for each of the scenarios.

Change in acceptance rates

Even if current age-specific acceptance rates apply (low acceptance rate scenario), there will be growth in the demand for RRT of an average 2.6% p.a. (Figure 2). Increasing the acceptance rate to meet additional need (Medium and Base scenarios) produces even higher growth. The future prevalence of RRT by 2010 is estimated to be in the range 42 000–48 000 cases depending on the acceptance rate, a prevalence rate of ~850–950 p.m.p. The largest changes are in the elderly and those on HD: in the Base scenario there is a doubling in those over 65 to nearly 16 000 patients and the number on HD is predicted to increase from approximately 11 600 to 18 300. The effect of increasing diabetic ESRF incidence is relatively small.

Age distribution

Figure 3 shows that the proportions of patients over age 65 increase in all scenarios, from a current 24% (RS) to about 33%; estimated mean numbers increase even more sharply, from 7920 (RS) to an estimated 15 648 in 2010 (Base scenario). The proportions of patients over age 65 are much higher for dialysis (47–49%) than for functioning grafts (16–17%), and the proportions over age 75 are 21–24 and 3%, respectively, for these modes.

Transplant supply

Figure 4 shows that achieving the UKT targeted increase (High transplant scenario) in donor organs by 2005 does not affect the total numbers significantly but reduces the proportion on dialysis. For example the proportion falls from 58% if there is no increase in transplant supply to 50% if the UKT plan is achieved, a difference of over 3000 patients on dialysis. However, the transplant waiting list still increased from 4228 to 5224 for this scenario, because of the demand from the existing waiting list and increased input from the rising acceptance rates. Table 3 shows transplant supply has little effect on the age distribution.

Patient survival

Figure 4 also shows the impact of improved patient survival on HD (High HD survival scenario). The total number increases from approximately 8000 in the Base scenario to almost 21 000 even with an increase in transplant supply.

Dialysis choice

Increasing the proportion of incident patients starting HD and reducing those starting PD (Choice scenario) increased the overall number on HD by approximately 700, a 4% increase over the standard Base scenario (Figure 4).

Starting position

Changing the initial starting stock from 33 307 (RS) to 29 312 (RR) (RR scenario) and acceptance rates from 104 (RS) to 94 p.m.p. (RR) (Figure 4) reduces the total number on RRT at 2010 by nearly 4000 patients (from 48 170 to 44 500). This significant effect may be partly due to the higher age distribution in the RR scenario.

Steady state

Figure 5 shows the impact of running the model for longer than 10 years using the Base scenario, on the assumption that all parameters stay the same after 2010 (and it therefore does not take account of changes in population, acceptance rates or survival after 2010). RRT growth continues, though at a declining rate, so that by 25 years the total number of RRT is nearly 60 000 patients and beyond that time a steady state appears to be reached. At 25 years the proportion

Table 3. Summary of estimated RRT demand from various scenarios

Factors tested	Scenario used	2010 Acceptance rate	2010 Stock number patients	2010 stock (p.m.p.)	Annual RRT % growth	Number on HD	% on dialysis	Annual HD % growth	$n > 65$ years	% > 65 years
	Base	162	48 170	961	4.5	18 343	52	5.9	15 559	32.3
Acceptance rate	Low AR	115	42 570	849	2.8	14 542	45	2.6	13 239	31.1
	Medium AR	125	43 704	872	3.1	15 374	47	3.3	13 854	31.7
Diabetic ESRD incidence	10% > Diabetes	168	48 471	967	4.6	18 568	52	6.1	15 705	32.4
	50% > Diabetes	173	49 334	984	4.8	19 300	53	6.6	16 379	33.2
Transplant supply	Low transplant	162	47 472	947	4.3	20 076	58	7.4	15 476	32.6
	High transplant	162	48 407	966	4.5	17 943	50	5.5	15 635	32.3
Patient survival	High HD surv	162	50 951	1016	6.2	20 976	54	8.1	17 323	34.0
Dialysis choice	Choice	162	48 045	958	4.4	19 047	51	6.5	15 519	32.3
Start position	RR	162	44 499	888	5.2	16 818	51	5.9	15 219	34.2

The RS starting position in 2000 is acceptance rate 104 p.m.p., stock 33 000 (660 p.m.p.), 51% on dialysis and 24% aged over 65 years. The RR starting position in 2000 is 29 312 (582 p.m.p.), 53% on dialysis and 28% aged over 65 years.

aged > 65 years increases to 35%. Even in projections based on current acceptance rates in England the steady state approaches 50 000 patients.

Minimum and maximum future demand

We also ran two scenarios to estimate the minimum and maximum future demand for dialysis. The 'minimum' scenario used the low acceptance rate with the high transplant supply, the lower 'RR' starting stock and no increase in diabetic ESRD incidence or HD survival. The 'maximum' scenario used the Base acceptance rate with the low transplant supply: RS starting stock, 50% increase in diabetic ESRD and improved HD survival. The estimated total on RRT with the minimum scenario was 37 300 the maximum was 51 500 a 13 and 56% increase over 2000 RRT numbers, respectively. The proportions on HD for these two scenarios were 34 and 56%, respectively.

Discussion

Even without any increase in the current acceptance rate, the numbers on RRT in England are predicted to rise substantially over the decade by an average of ~2.6% p.a.. The ageing of the ethnic minority population accounts for a predicted increase in acceptance rate from an estimated current 104 to 115 p.m.p. by 2010. This changing demography, together with scenarios in which acceptance rates increase to meet unmet need, predict a further large increase in RRT, predominantly in HD. For example, a simulation of the Base scenario based on the year 2000 acceptance rate in Wales with a pragmatic increase in transplant supply predicts a prevalent number of 48 000 patients by 2010, with largest absolute increase being in the elderly, the prevalent rate approaching 1000 p.m.p. However, over 50% of the growth would occur even if current acceptance rates persist.

It is difficult to be certain about the future acceptance rate or its rate of change. The age specific acceptance rates assumed for 2010 in the Base scenario were similar to rates from Austria (129 p.m.p.), Belgium (144 p.m.p.), Greece (154 p.m.p.), Canada (143 p.m.p.) and Spain (132 p.m.p.) found in 2000 [13]. In view of the apparent levelling off of acceptance rates discussed in the introduction, the UK trends in acceptance rate need to be reviewed over the next few years [14]. Our analysis indicates that it is likely that there is unmet need amongst the current population, and this, along with population factors, which will increase the underlying incidence of ESRD such as the ageing of the ethnic minority population, will give rise to a continuing increase in the acceptance rate. Indeed, most other developed countries, including those with higher acceptance rates than the UK, have seen continuing increases in acceptance rates [15,16]. Although rates in the USA, where acceptance rates are highest, may be levelling off [17]. It is even possible that we have underestimated

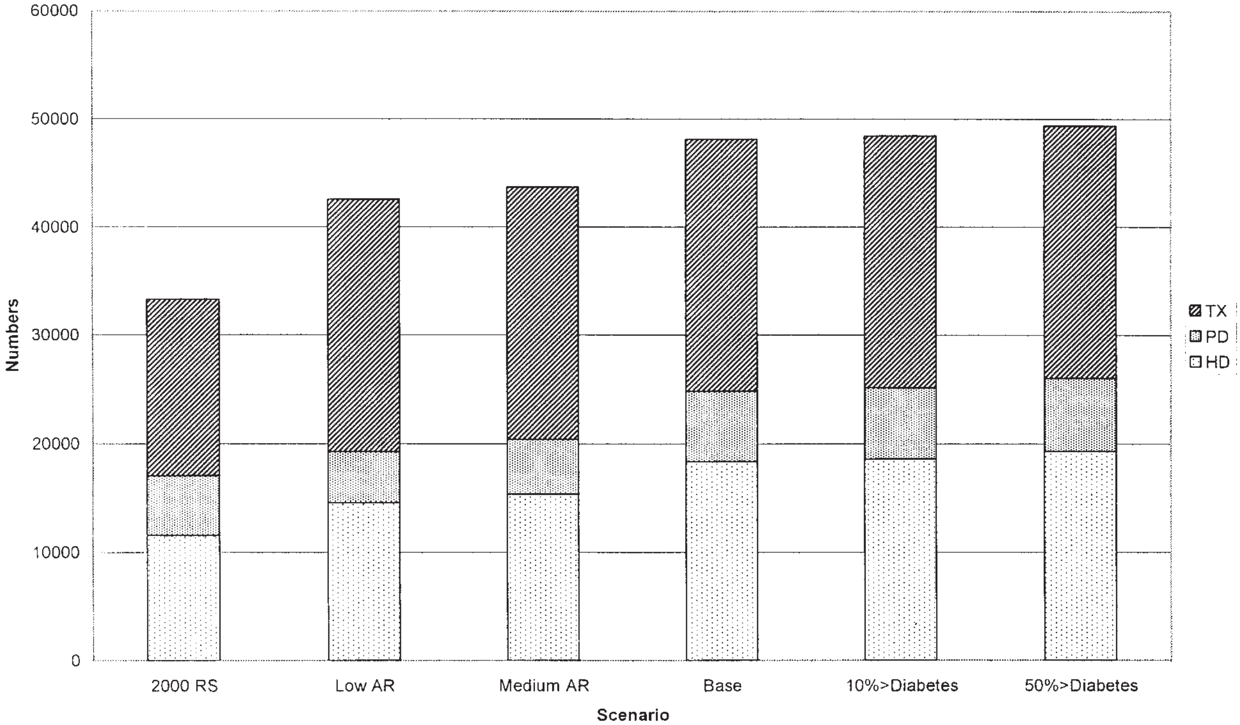

Fig. 2. Projected mean numbers on RRT in 2010 for different estimates of future acceptance rates by mode using the pragmatic transplant increase assumption.

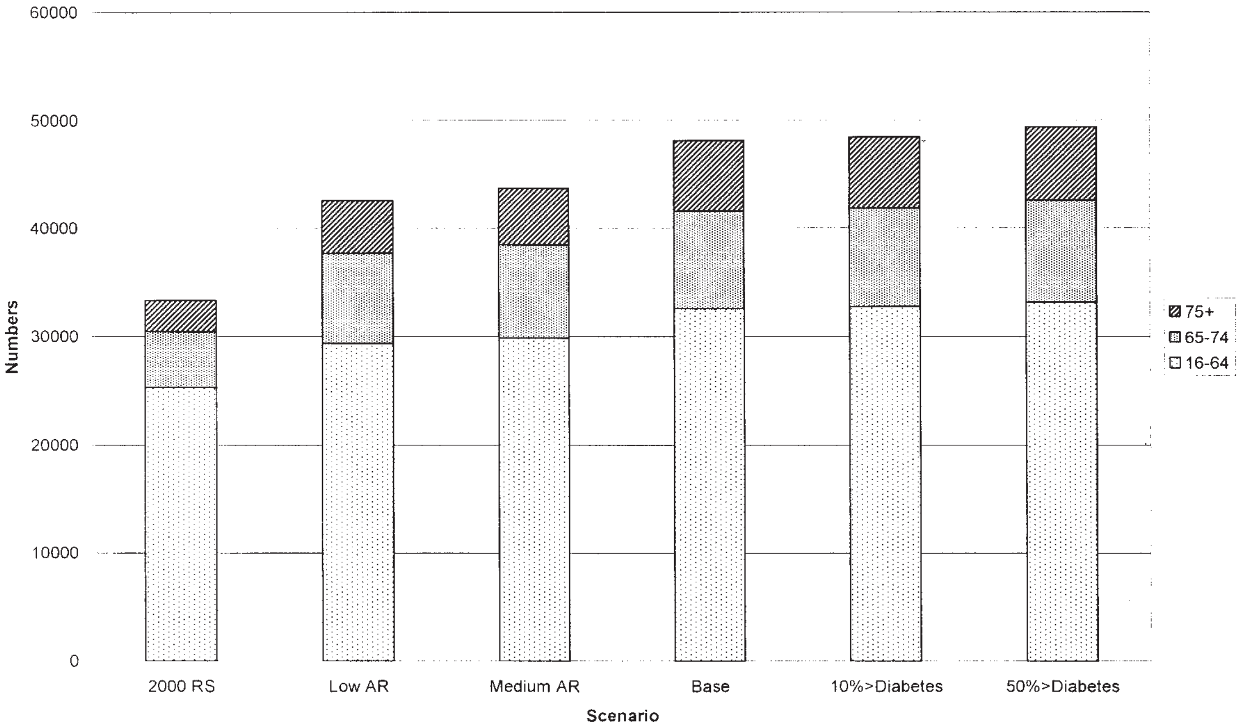

Fig. 3. Projected mean numbers on RRT in 2010 for different estimates of future acceptance rates by age using the pragmatic transplant increase assumption.

future growth in acceptance rates. The forthcoming National Service Framework for Renal Services in England will provide an impetus for expansion of RRT [18] to meet the expected future demand.

It is predicted that there will be a substantial rise in the incidence and prevalence of Type 2 diabetes over the coming decades. We have made an attempt at estimating the impact of this epidemic. The diabetic

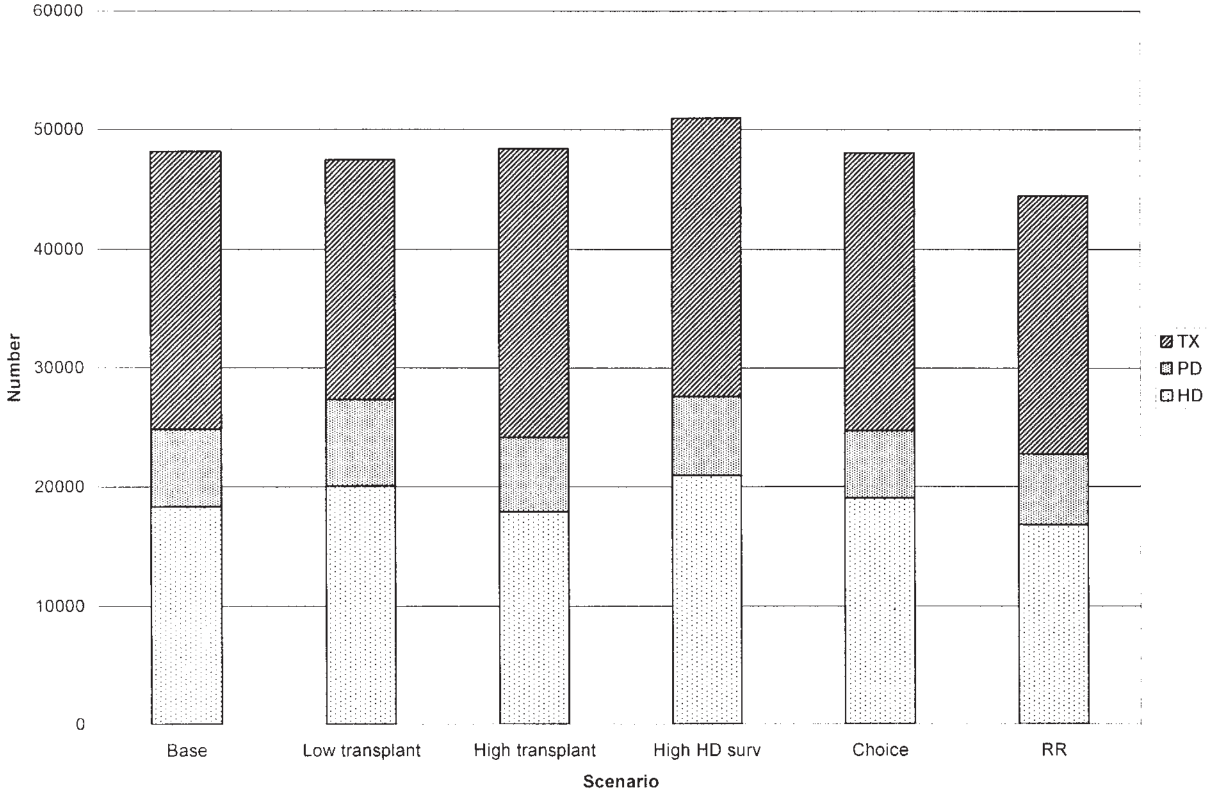

Fig. 4. Projected mean numbers on RRT in 2010 by mode for different estimates of transplant supply (Low and High), patient survival (High HD surv), choice of mode (Choice) and starting position (RR).

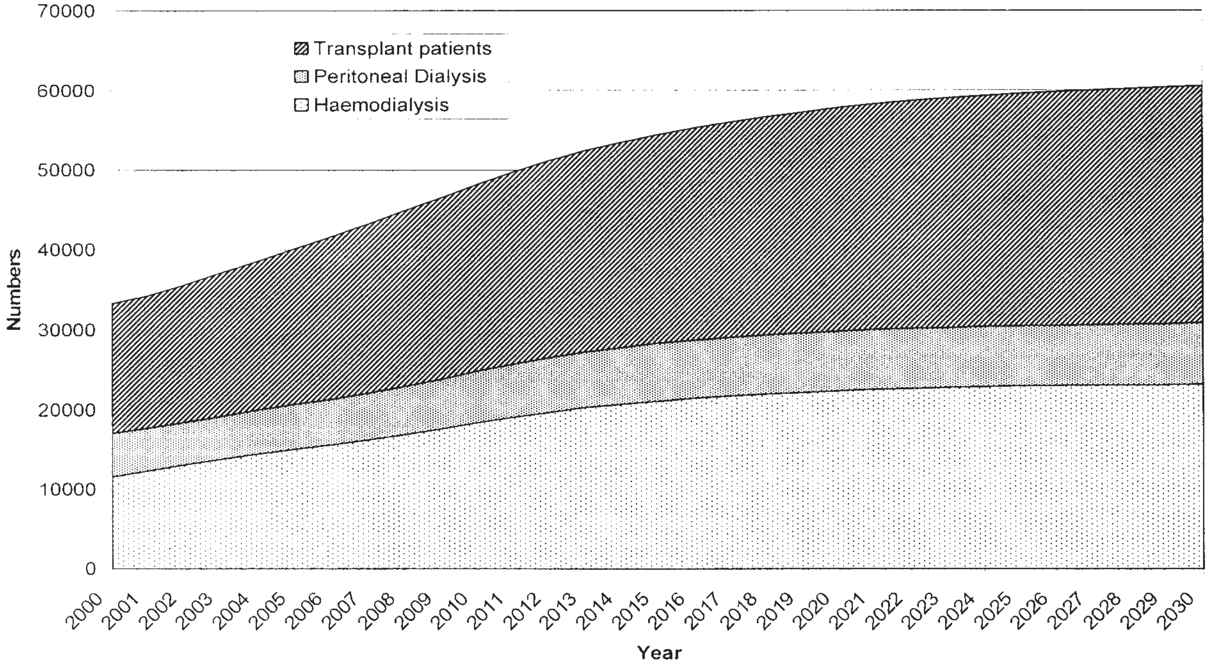

Fig. 5. Projected mean numbers on RRT between 2000 and 2030 by mode, using Base scenario.

ESRF acceptance rates predicted in 2010 with the 50% increase are similar to the current rates in countries (e.g. New Zealand, Austria) with the highest rates outside of the US. The key question is whether the transition to diabetic ESRF can be prevented or reduced by more effective management. There is good evidence that progression can be reduced by effective control of glycaemia and hypertension and by the use of ACE inhibitors. However, most countries are seeing rises in the diabetic ESRF rate and this coupled with the likely unmet need in diabetics, may on balance prevail and increase the demand for RRT. Despite this, the impact on overall stock was not substantial because those with diabetic ESRF have poorer survival. Furthermore, earlier referral and better pre-ESRD management may delay or even prevent progression to RRT for all types of chronic kidney disease and hence may reduce demand. However, as patients would reach end-stage renal failure in a better clinical and psychological state, the countervailing effect of reducing the risk of death from competing causes and improved survival on RRT may occur. The future trends in acceptance rates and patient survival clearly need to be kept under review to assess these potential effects.

Increasing the transplant supply, as targeted by UKT, has a small effect on overall numbers as there is slightly better patient survival but the main effect is to change the proportion of patients with a transplant, with the proportion on dialysis falling from 58 to 50% if the target is reached. However, the predominant growth will be in HD even with increasing transplant supply.

Despite the increasingly elderly and co-morbid patients being accepted for RRT, there is the possibility that patient survival will continue to improve, partly due to the dissemination of national standards [4] and feedback of audit data to renal units by the UK Renal Registry. However, although there is evidence of improvement over time in some measures of dialysis performance, which might impact on survival, published data from national and international renal registries suggest that survival on dialysis has remained largely stable for some time [19]. We showed that if survival were to improve, it would have a significant effect on overall stock, with the number increasing by approximately 3000 (5%) over our Base scenario. Trends in dialysis survival will be produced by the UKRR and can be taken into account in future modelling. Likewise further work is needed to evaluate the effect of possible changes in transplant survival.

There is a relative lack of HD facilities in certain areas in England at present, possibly causing an artificially high number of patients on PD. An increase in patient choice is expected to increase the take up of HD with respect to PD [12]. If HD facilities expand and we assume a higher HD to PD ratio at the start then we can expect a small change in the long-term balance between HD and PD.

The model used here is an update of an earlier model, which uses newer data on treatment patterns and transitions from national databases UKT and UK Renal Registry, and is able to explore different patterns of dialysis and make more realistic assessments of future acceptance rates. We have had to make several assumptions to simplify the model. To adjust for the increased demand from ethnic minorities we used the age and ethnicity specific relative risks from the 1991/2 National Renal Review [2]. Because the demand estimates are uncertain, we have provided a range of estimates based on different assumptions about unmet need. As co-morbidity data are incomplete in the UK Registry, diabetic ESRF has been used as a proxy for predicting patient survival. The independent effect of diabetes is, however, much weaker in older age groups, the groups in which the most growth is expected. The exact current acceptance and stock rates in England are unknown because the UK Renal Registry only has partial coverage. The UK Renal Registry will be able to provide robust demographic and outcome data as more units are recruited and as follow-up times increase. Such data can be incorporated on a regular basis into the model. We have not separated home and hospital HD, home HD currently being $<3\%$ of dialysis pool, and have assumed no change in the timing of initiation of RRT.

There have been a variety of other modelling approaches, such as extrapolation of trends and Markov models, used to predict future RRT demand in various countries [20–25]. Our findings are consistent with these, with all predicting continued growth, particularly in the elderly [22]. These include countries with both significantly higher acceptance rates than England (Canada [24], USA [25]) and similar acceptance rates (Denmark [23], Australia [22]). An Australian model [22] showed the beneficial effect of increasing transplant supply on the balance of modes. Growth in RRT was shown to be sensitive to future acceptance rates [22,23]. The advantages of the simulation model, particularly over trend analysis, are that it is possible to take account of risk factors and to independently vary prevalent patient numbers, acceptances, treatment availability and survival probabilities. It also provides an independent source of transplants that can be allocated to prioritized patient groups.

In summary, we have developed a model, which predicts a continued and substantial growth in the national RRT population to over 45 000 patients by 2010, with the steady state position not being reached for over 25 years. This is due to inbuilt growth even at current acceptance rates, increases in acceptance rates from health care policies aimed at better meeting need for RRT, and changes in the epidemiology of ESRD from the rising incidence of Type 2 diabetes and demographic shifts. Transplant supply does have an impact on the dialysis to transplant ratio but, even with optimistic projections of the future supply, still there is likely to be substantial increase in the need for HD delivered to all patient age groups but especially to an elderly co-morbid group of patients. Funding for RRT provision will have to grow to meet demand.

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