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Cost-effectiveness analysis of renal replacement therapy in Austria

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Abstract

Background. Providing renal replacement therapy (RRT) for end-stage renal disease patients is resource intensive. Despite growing financial pressure in health care systems worldwide, cost-effectiveness studies of RRT modalities are scarce.

Methods. We developed a Markov model of costs, quality of life and survival to compare three different assignment strategies to chronic RRT in Europe.

Results. Mean annual treatment costs for haemodialysis were €43 600 during the first 12 months, €40 000 between 13 and 24 months and €40 600 beyond 25 months after initiation of treatment. Mean annual treatment costs for peritoneal dialysis were €25 900 during the first 12 months, €15 300 between 13 and 24 months and €20 500 beyond 25 months. Mean annual therapy costs for a kidney transplantation during the first 12 months were €50 900 from a living donor, €51 000 from a deceased donor, €17 200 between 13 and 24 months and €12 900 beyond 25 months after engraftment. Over the next 10 years in Austria with a population of 8 million people, increased assignment to peritoneal dialysis of 20% incident patients saved €26 million with a discount rate of 3% and gained 839 quality-adjusted life years (QALYs); additionally, increasing renal transplants to 10% from live donations saved €38 million discounted and gained 2242 QALYs.

Conclusions. Live donor renal transplantation is cost effective and associated with increase in QALYs. Therefore, preemptive live kidney transplantation should be promoted from a fiscal as well as medical point of view.

Keywords: cost-effectiveness analysis; dialysis; kidney transplantation; Markov model; renal replacement therapy

Introduction

Providing health care for end-stage renal disease (ESRD) patients is complex and resource intensive, requiring considerable amounts of limited health care funding. The continual global growth in the chronic renal failure population and rising interest in economic expenses in health care resources demand a more cost-effective approach to medical decision making.

Renal replacement therapy (RRT) is available in three different modalities, haemodialysis (HD), peritoneal

dialysis (PD) and kidney transplantation from either a living donor (TL) or a brain-dead donor (TD). Kidney transplantation offers a nearly normal life in both, quality of life and survival, and is considered the optimum treatment for eligible patients [1]. Despite renal transplants from live donors, organ shortage remains a worldwide problem producing increasing waiting lists for transplantation and an inevitable necessity for dialysis treatments [2, 3]. Compared to renal transplantation, dialysis is less effective in terms of 'survival' and 'quality of life' [4–8].

Economic evaluations of renal replacement treatment modalities have come into focus and gain ever more impact on medical decision making. Despite growing economic pressure on the collective health care system, cost-effectiveness studies of managing ESRD treatment are scarce. Most of the published studies focus solely on evaluating parts of RRT, such as different dialysis modalities compared to one another or a certain dialysis modality compared to transplantation [2, 3, 9–15]. Only a few have evaluated the cost effectiveness of all available treatment modalities for ESRD [16, 17]. Furthermore, cost data in several studies are based on annual accounts of dialysis departments, average health insurance payments for ESRD treatment or the published literature [3, 10, 12].

Hence, this study sought to elucidate the cost effectiveness of RRT alternatives based on individual cost data.

Material and methods

We developed a Markov model of costs, quality of life and survival to compare three different assignment policies to chronic renal replacement treatment modalities over a 10-year period in Austria from a public health perspective. The main outcome measure was costs per quality-adjusted life years (QALYs). Our decision analytic model was designed to evaluate the cost effectiveness of the current Austrian assignment policy to chronic RRT according to data from the Austrian Dialysis and Transplant Registry. This approach was compared to two alternative strategies with an increased allocation of 20% of the ESRD patients to peritoneal dialysis in Strategy 2 or 20% of new patients with chronic kidney failure allocated to peritoneal dialysis and additional 10% receiving a kidney transplant from a living donor in Strategy 3. Markov models are frequently used to estimate cost and benefits of various treatment strategies [18]. The model describes the dynamics in the Austrian ESRD population that was attributed to 10 different states depending on time of initiation of a certain treatment modality: 'HD' for haemodialysis during the first 12 months, 'HP' for haemodialysis between 13 and 24 months, 'HM' for haemodialysis beyond 25 months, 'PD' for peritoneal dialysis during the first 12 months, 'PP' for peritoneal dialysis between 13 and 24 months, 'PM' for peritoneal dialysis beyond 25 months, 'TD' for kidney transplantation from a deceased donor during the first 12 months, 'TL' for kidney transplantation from a living donor during the first 12 months, 'TP' for kidney transplantation between 13 and 24 months and 'TM' for a kidney transplant beyond 25 months (Figure 1). Each state in the model is defined by quality of life and costs.

A Markov model estimates patient numbers in each state of the model in the future based on the prevalence (present distribution), incidence [inflow of new ESRD patients who are represented in the initial (Init) state] and transition probabilities (transition probabilities between the states indicated by the arrows in Figure 1 represent, for example the frequency of transplantation or the frequency of graft failure depending on the current health state).

Strategies

Strategy 1 represents the current assignment policy in Austria. 90.6% of new ESRD patients were treated with haemodialysis, 7.2% with peritoneal dialysis, 0.1% received a renal transplantation from a live donor and 2.1% from a deceased donor [19].

The hypothetical alternative Strategy 2 was set as 20% of the incident, ESRD patients were allocated to peritoneal dialysis. In the other alternative Strategy 3, 20% of incident ESRD patients were allocated to peritoneal dialysis and additional 10% for preemptive renal transplant from a living donor.

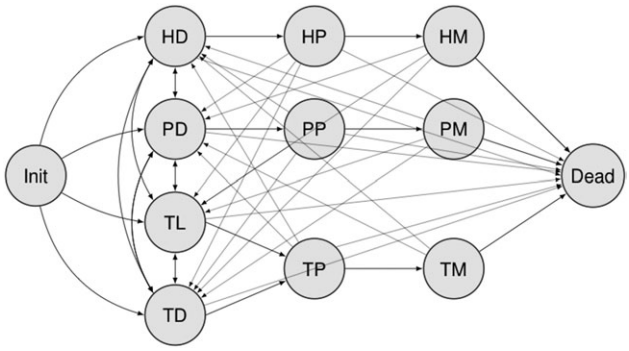

Fig. 1. State diagram for the Markov model. Circles represent states and arrows represent transitions between states. 'Init' stands for the initial state of a newly diagnosed kidney disease, 'HD' for haemodialysis during the first 12 months, 'HP' for haemodialysis between 13 and 24 months after initiation of treatment, 'HM' for haemodialysis beyond 25 months, 'PD' for peritoneal dialysis during the first 12 months after start of treatment, 'PP' for peritoneal dialysis between 13 and 24 months, 'PM' for peritoneal dialysis beyond 25 months, 'TL' for living-donor kidney transplantation during the first 12 months, 'TD' for deceased-donor kidney transplantation during the first 12 months, 'TP' for kidney transplantation between months 13 and 24 after engraftment, 'TM' for a kidney transplantation more than 25 months in the past and 'Dead' for the final state of death.

Data sources

Our Markov model was imputed with data on health care costs, transition probabilities and quality of life. Cost data were obtained from two sources, the Upper Austrian Health Insurance (OÖGKK) and the Elisabethinen Hospital Linz (EHL). The Upper Austrian Health Insurance is the public social security insurance in Upper Austria and covers the majority of the population and the EHL is among the leading providers of care for ESRD patients in Austria. Transition probabilities data were estimated from the Austrian Dialysis and Transplant Registry [19]. Data on quality of life were used from a previously published study [16].

Patient population

All patients used for collecting cost data for individuals on RRT in Austria were patients in the chronic RRT programme at the EHL. We included all patients who underwent chronic RRT at EHL between 1 January 2001 and 31 December 2008. We excluded patients <18 years. Table 1 gives a description of our study population.

Assessment of costs of RRT

All costs are reported in Euros and adjusted by an annual discount rate of 3% to correct for a lower contribution of future years compared to the net present value [20]. The assessment of costs was designed to include the total costs for patients on chronic RRT, including not only therapy-related costs but also all other health care expenditures, such as costs of transportation to the renal unit, costs of medication as well as all costs for non-ESRD-related admissions to the hospital for chest pain or fever for instance. We excluded reimbursements and charges for cost data collection. Only completed years were used to estimate the annual costs. Inclusion criteria for collecting cost data on transplant recipients was a functioning graft for >3 months. Costs were collected retrospectively from two different sources according to electronic patient records. Costs related to medical treatment were obtained from the financial service at the EHL. Costs of prescribed medication and transportation were obtained from the Upper Austrian Health Insurance. National costs from a societal perspective such as the patient's ability to work were not considered in the present study.

Cost data from the EHL were collected for each patient separately and contained total individual costs for each patient within our centre, such as costs for inpatient and outpatient treatments, management of complications, investigations, blood tests, medications received within the hospital

Table 1. Description of the patients from the Austrian dialysis and transplantation register that were used for the estimation of the model parameters (see Table 3)[a]

	Haemodialysis	Peritoneal dialysis	Kidney transplantation
a)			
Age, mean (SD)	61.5 (14.6)	47.1 (15.1)	48.1 (13.5)
Gender, % men	60.4	41.7	64.4
Comorbidities			
Diabetes, %	30.9	8.3	19.2
Hypertension, %	64.6	100	69.9
Heart diseases, %	48.4	16.7	26.0
Neoplasia, %	5.3	0.0	5.5
Liver diseases, %	10.9	0.0	6.8
Vascular diseases, %	50.4	33.3	26.0
COPD, %	19.7	25.0	11.0
b)			
Renal diagnosis	%		
Glomerulonephritis	26.2		
Diabetic nephropathy	22.4		
Vascular nephropathy	12.6		
Polycystic kidney disease	8.6		
Other	30.2		

[a]Part (a) shows the age distribution, the percentage of men and the comorbidities separately for each of the three renal replacement treatment modalities. Part (b) shows the percentage of the initial renal diagnoses at the time when patients were assigned to a RRT.

Table 2. Estimated costs (in €1000 per month) and effects (QALYs) with 95% confidence interval (CI), for each state of the Markov model[a]

Outcome parameter	Value	95% CI
Therapy costs (€1000/month)		
HD	3.630	3.462–3.801
HP	3.330	3.189–3.474
HM	3.380	3.225–3.539
PD	2.160	0.903–3.957
PP	1.530	0.392–3.429
PM	1.710	0.595–3.403
TL	4.240	3.755–4.754
TD	4.250	3.761–4.769
TP	1.430	1.161–1.726
TM	1.070	0.702–1.515
Monthly QALY gains		
HD, HP, HM	0.055	0.018–0.112
PD, PP, PM	0.068	0.034–0.112
TL, TD, TP, TM	0.075	0.039–0.123

[a]Data from the Elisabethinen Hospital Linz and from the Upper Austrian Health Insurance were used for the cost parameters. Therapy costs include costs for inpatient and outpatient treatment, including non-ESRD-related admissions, costs for medications, including ESAs and i.v. iron, costs for transportation to the renal unit as well as costs for RRT itself. Costs were distinguished between the first year (0–12 months), the second year (13–24 months) and subsequent years (beyond 25 months) after initiation of the treatment for haemodialysis, peritoneal dialysis and kidney transplantation. Therapy costs for kidney transplantation during the first 12 months were furthermore separated depending on the donor source (living donor or deceased donor). Results from the questionnaire by de Wit *et al.* [16] were used for the QALY outcome parameters. The CIs are used for the sensitivity analysis (see Figure 3) and are based on Gamma distributions. HD, haemodialysis during the first 12 months; HP, haemodialysis between 13 and 24 months after initiation of treatment; HM, haemodialysis beyond 25 months; PD, peritoneal dialysis during the first 12 months after start of treatment; PP, peritoneal dialysis between 13 and 24 months; PM, peritoneal dialysis beyond 25 months; TL, living-donor kidney transplantation during the first 12 months; TD, deceased-donor kidney transplantation during the first 12 months; TP, kidney transplantation between 13 and 24 months after engraftment; TM, kidney transplantation beyond 25 months. Treatment costs include the total annual costs for patients on chronic RRT, including therapy-related costs, costs for inpatient and outpatient treatment, costs of transportation to the renal unit, costs of medication and costs for non-ESRD-related admissions. Only completed years were used to estimate the annual costs.

including expensive drugs such as erythropoiesis stimulation agents (ESAs) and various immunosuppressants, radiological imaging procedures, consultations, nursing, supplies as well as all overhead costs such as costs for maintenance, physician and nurse fees, hospital administration, laundry, equipment and building acquisition.

Cost data from the Upper Austrian Health Insurance was collected for all our patients with insurance coverage at the Upper Austrian Health Insurance and included total costs for prescribed pharmaceuticals for outpatient treatment and transportation to the renal unit for each individual patient.

As the vast majority of HD patients in Austria are treated with centre haemodialysis (CHD), three times per week total haemodialysis-related costs including costs for haemodialysis treatment, ESAs and i.v. iron account for the cost data obtained from the EHL.

Most PD patients in Austria perform continuous cyclic peritoneal dialysis (CCPD). Therefore, data on expenditures for peritoneal dialysis patients represents cost of this PD method.

In order to compare cost effectiveness of renal transplantation depending on the donor source, we included costs of kidney donation and organ harvesting. In the case of a live donation, we collected costs of the mandatory potential donor health check as well as costs of the hospital stay for donor nephrectomy and regular outpatient checks after donation for each live donation performed in our centre since 1 January 2006. In none of the cases of living donation, did we have to check more than one potential donor for eligibility.

For kidneys which derived from deceased donors, we were unable to collect accurate costs for kidney harvesting since deceased donation is a complex system of transnational organ sharing within Eurotransplant. We anticipated that there would be a difference in costs depending on whether the kidney was from a local donor or flown in by plane from another Eurotransplant member country. On average, a deceased organ donor remains 2 days on intensive care units (ICU) in Austria (Udo Illievich, Rainer Oberbauer) between the decision to call for neurologists to determine whether the potential donor is brain dead or not and organ harvesting. We calculated the average expenditure for 1 day on a surgical ICU from our hospital records and assumed the costs of 2 days of intensive care treatment would be the closest we could get to the true costs of kidney donation from a brain-dead donor based on the current available data.

Assessment of quality of life

Quality of life outcomes are reported in QALYs which is a measure of disease burden including quality and quantity of life lived against monetary value, medical treatment or intervention. We used results of the questionnaire by de Wit *et al.* [16]. One hundred and sixty-five dialysis patients of >18 years and who were receiving at least 3 months of same renal replacement treatment modality were interviewed in this study using the following instruments: EuroQol (EQ-5D) [21, 22], Standard Gamble [23] and Time Trade Off [24]. Since CHD and CCPD are the leading treatment forms among our study population, we used quality of life values for CHD and CCPD, which was 0.66 for CHD and 0.81 for CCPD as reported by de Wit *et al.* [16] (Table 2).

Kidney transplant patients were not interviewed by de Wit but quality of life for renal transplant recipients was estimated based on the literature [2, 4, 25]. These studies could show a quality of life of patients with a functioning kidney graft close to that of the general population. In addition, successfully transplanted patients experience a 23% increase in Time Trade Off scores compared to dialysis [2]. Based on these findings, de Wit reported a quality of life factor for transplanted patients of 0.9, which we applied to our study population.

Assessment of survival probabilities and transition probabilities of RRT

For survival and transition probabilities, we received data for the Austrian ESRD population between 1, January 2005 and 31, December 2008 from the Austrian Dialysis and Transplant Registry that collects data from all Austrian dialysis and transplant patients [19]. Based on these data, probabilities for patients on chronic RRT to switch states or stay on their current treatment were calculated per month for our model.

Statistical methods

For the present study, we used a Markov model to estimate costs and QALYs over the next 10 years in Austria. Conceptually, in a Markov model, each patient is in one of several possible health states. During each month, a patient creates costs and QALYs depending on his health state. At the end of a month, the patient may switch from his current state to another state with a certain transition probability. Each month, new patients are added with constant incidence rate to an 'Init' state from where they are assigned to haemodialysis, peritoneal dialysis, living-donor transplantation or deceased-donor transplantation.

To allow us to use monthly cycles in the Markov model, some of the states are conceptually split into 12 identical states, 1 for each month. For example, the state HD (haemodialysis during the first year) is represented by the states HD_1, HD_2, ..., HD_{12}. A patient assigned to haemodialysis starts in state HD_1. If no transition to another state occurs, the patient moves to the stage HD_2 in the next month. Finally, if no transition occurs in state HD_{12}, the patient moves to the state HP (haemodialysis during Months 13–24), which itself is split into the identical states HP_1, HP_2, ..., HP_{12}.

Since we used monthly transitions and we wanted to estimate the development in Austria over the next 10 years, the model was run for 120 cycles.

Transition probabilities and survival probabilities were estimated by a multinomial model on the transitions of renal patients in Austria between 2005 and 2008 that are recorded in the Austrian dialysis and transplantation register. The baseline prevalence at the end of 2008 was used as an estimate for the baseline prevalence. Finally, the incidence rate was estimated by Poisson regression (without covariables) on the monthly data from 2005 to 2008.

We calculated Goodman's simultaneous 95% confidence intervals for transition probabilities and for baseline prevalence, as well 95% confidence intervals for the incidence rate based on the Poisson distribution [26]. For costs, 95% confidence intervals were obtained based on Gamma distributions [27].

We performed a sensitivity analysis for policy parameters and a sensitivity analysis for model parameters. Concerning policy parameters, we repeated the calculations of the Markov model with a range of values for peritoneal dialysis assignment proportion and for living-donor transplantation proportion and compared the resulting costs and the QALYs to the current assignment policy. Concerning the model parameters, we performed a tornado sensitivity analysis in which model parameters are individually varied over plausible ranges and the resulting cost and benefit intervals are ordered by decreasing length to obtain a measure of the relative influence of the respective model parameters [28].

Results

Costs

A summary of treatment costs is also given in Table 2. Total costs per year for HD during the first 12 months averaged €43 600 mean (SD €13 000), for HP between 13 and 24 months €40 000 mean (SD €10 900) and for HM beyond 25 months €40 600 mean (SD €12 000). Total costs per year for PD during the first 12 months were €25 900 mean (SD €21 800), for PP between 13 and 24 months €15 300 mean (SD €22 000) and for PM beyond 25 months €20 500 mean (SD €20 200). Mean total costs of kidney transplantation during the first 12 months were €50 900 (SD €12 200) from a living donor and €51 000 (SD €24 100) from a deceased donor and included costs for the procurement of the donor kidney (€9700 for a living donation and €3100 for a deceased donation). In addition, a registration fee to Eurotransplant of €588 is mandatory for patients undergoing kidney transplantation from a deceased donor. Mean total costs of a kidney transplantation were €17 200 (SD €13 000) between 13 and 24 months and €12 900 mean (SD €12 500) beyond 25 months after transplantation.

Table 3. Expected incidence, prevalence and transition probabilities with 95% confidence interval (CI), estimated from the Austrian dialysis and transplantation register 2005 to 2008[a]

Parameter	Value	95% CI
Monthly incidence rate	103	93–114
Baseline prevalence (‰)	0.16	0.13–0.21
HD		
HP	0.11	0.08–0.15
HM	0.15	0.17–0.19
PD	0.01	0.00–0.2
PP	0.01	0.00–0.20
PM	0.02	0.00–0.80
TL	0.01	0.00–0.01
TD	0.04	0.02–0.08
TP	0.08	0.03–0.39
TM	0.43	0.21–0.75
Monthly transition probability (%)		
HD → HD/HP	97.07	96.82–97.30
HD → PD	0.35	0.28–0.44
HD → TL	0.15	0.10–0.22
HD → TD	0.22	0.16–0.30
HD → Dead	2.21	2.01–2.43
HP → HP/HM	97.91	97.61–98.17
HP → PD	0.05	0.02–0.12
HP → TL	0.06	0.03–0.13
HP → TD	0.43	0.32–0.58
HP → Dead	1.55	1.33–1.81
HM → HM	98.20	97.84–98.50
HM → PD	0.03	0.01–0.11
HM → TL	0.02	0.00–0.10
HM → TD	0.54	0.38–0.76
HM → Dead	1.21	0.96–1.52
PD → PD/PP	96.76	95.93–97.42
PD → HD	1.52	1.09–2.12
PD → TL	0.13	0.04–0.39
PD → TD	0.65	0.39–1.08
PD → Dead	0.94	0.61–1.44
PP → PP/PM	97.13	95.97–97.96
PP → HD	0.97	0.54–1.74
PP → TL	0.13	0.03–0.58
PP → TD	1.15	0.67–1.97
PP → Dead	0.62	0.30–1.29
PM → PD/PP	96.27	94.37–97.55
PM → HD	1.56	0.82–2.96
PM → TL	0.00	0.00–0.68
PM → TD	1.04	0.47–2.27
PM → Dead	1.13	0.53–2.39
TL → TL/TP	99.92	99.25–99.99
TL → Dead	0.08	0.01–0.75
TD → TD/TP	99.54	99.08–99.77
TD → HD	0.34	0.15–0.23
TD → Dead	0.12	0.03–0.44
TP → TP/TM	99.84	99.44–99.95
TP → HD	0.04	0.00–0.37
TP → Dead	0.12	0.03–0.50
TM → TM	98.00	96.56–98.85
TM → HD	1.00	0.46–2.15
TM → Dead	1.00	0.46–2.15

[a]The CI are used in the sensitivity analysis (see Figure 3). For the incidence rate, the CI is based on the Poisson distribution. For prevalence and transition probabilities, Goodman's simultaneous CIs for the multinomial distribution are used. HD, haemodialysis during the first 12 months; HP, haemodialysis between 13-24 months after initiation of treatment; HM, haemodialysis beyond 25 months; PD, peritoneal dialysis during the first 12 months after start of treatment; PP, peritoneal dialysis between 13 and 24 months; PM, peritoneal dialysis beyond 25 months; TL, living-donor kidney transplantation during the first 12 months; TD, deceased-donor kidney transplantation during the first 12 months; TP, kidney transplantation between 13 and 24 months after engraftment; TM, kidney transplantation beyond 25 months.

Table 4. Estimated total cost savings (€1000) and effect gains (QALYs, quality unadjusted life years and YFD) over the next 10 years in Austria by two strategies compared with the current policy of assigning 90.6% of new renal disease patients to HD, 7.2% to PD, 0.1% to TL and 2.1% to TD[a]

Strategy	Total cost[b]	Total LYS	Total YFD	Total QALY	Δ costs[c]	Δ LYS[d]	Δ YFD[e]	Δ QALY[f]
Undiscounted								
Baseline	9165	294 741	117 380	230 820				
Increasing PD to 20%	9134	295 601	117 981	231 839	−31	860	601	1018
+ Increasing TL to 10%	9120	296 917	121 929	233 541	−45	2176	4549	2721
Discounted								
Baseline	8083	259 731	103 387	203 407				
Increasing PD to 20%	8057	260 435	103 875	204 245	−26	704	488	839
+ Increasing TL to 10%	8046	261 511	107 157	205 648	−38	1780	3770	2242

[a]Results are shown both undiscounted and discounted with an annual discount rate of 3%.
[b]Total costs in million Euros.
[c]Incremental costs in million Euros.
[d]Incremental LYS.
[e]Incremental YFD.
[f]Incremental QALYs.

Survival and transition probabilities

Survival and transition probabilities are presented in detail in Table 3. The baseline prevalence was 0.42‰ to be on haemodialysis treatment (0.16‰ HD, 0.11‰ HP and 0.15‰ HM) but 0.04‰ to be in a peritoneal dialysis programme (0.01‰ PD, 0.01‰ PP and 0.02‰ PM). The baseline prevalence to live with a functioning graft from a donor was 0.56 (0.01‰ TL, 0.04‰ TD, 0.08‰ TP and 0.43‰ TM). The monthly probability to stay on the current treatment modality is >96% in any state. The monthly probability to receive a kidney transplant during the first 12 months of dialysis treatment was 0.15% for HD and 0.13% for PD from a living donor and 0.22% for HD and 0.65% for PD from a deceased donor. The monthly probability to get a renal transplant between 13 and 24 months of dialysis treatment was 0.06% for HP and 0.13% for PP from a living donor and 0.43% for HP and 1.15% for PP from a brain-dead donor. Beyond 25 months of dialysis treatment, the monthly probability to receive a kidney transplantation was 0.02% for HM and 0% for PM from a living donor and 0.54% for HM and 1.04% for PM from a deceased donor. Monthly graft survival was >99% for TL, TD and TP and 98% for TM. The monthly death rate was higher in all three haemodialysis statuses compared to peritoneal dialysis statutes (2.21% for HD, 1.55% for HP, 1.21% for HM versus 0.94% for PD, 0.62 for PP, 1.13% for PM) and was lowest in all kidney transplant statuses (0.08% for TL, 0.12 for TD, 0.12 for TP and 1% for TM).

Cost effectiveness of chronic RRT

Results of the cost-effectiveness analysis are presented in Table 4. Total costs discounted were €8083 million for Strategy 1 (current HD-dominated assignment policy), €8057 for Strategy 2 (increasing PD to 20%) and €8046 for Strategy 3 (additionally increasing TL to 10%) saving €26 million with Strategy 2 and €38 million with Strategy 3 over the next 10 years. Total life years saved (LYS) were 259 731 years discounted for Strategy 1, 260 435 years for Strategy 2 and 26 1511 years for Strategy 3 gaining 704 LYS with Strategy 2 and 1780 LYS with Strategy 3 over the next 10 years. Total years free of dialysis (YFD) were

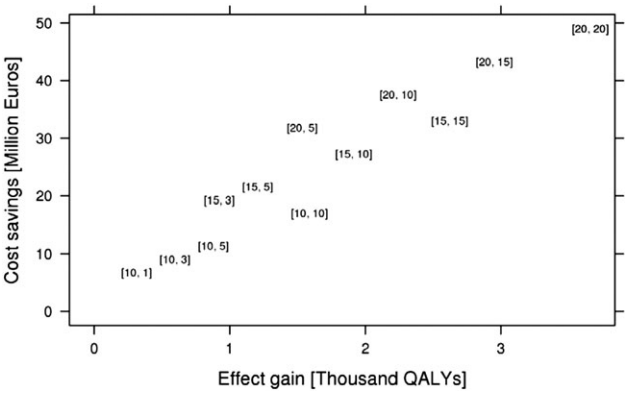

Fig. 2. Discounted savings (in million Euros) and discounted gains (in thousand QALYs) over the next 10 years for different policies compared to the current policy (annual discount rate 3%). Each bracket represents a policy, where the first number in the bracket represents the PD assignment proportion in per cent and the second number the living-donor transplantation proportion in per cent. For example, the bottom-left point '[10, 1]' represents the policy of assigning new renal patients in proportions 86.9, 10, 1 and 2.1%, to HD, PD, TL and TD, respectively.

103 387 years discounted for Strategy 1, 103 875 years for Strategy 2 and 107 157 years for Strategy 3 gaining 488 YFD with Strategy 2 and 1780 YFD with Strategy 3 over the next 10 years. Total QALY were 203 407 years discounted for Strategy 1, 204 245 years for Strategy 2 and 205 648 years for Strategy 3 gaining 839 QALY with Strategy 2 and 2242 QALY with Strategy 3 over the next 10 years.

Sensitivity analysis

Results of the sensitivity analysis for policy parameters are shown in Figure 1. It can be seen that cost savings and gains in QALYs increase steadily in both the proportion of PD assignments as well as the proportion of living-donor transplantation. Results of the tornado sensitivity analysis for the model parameters are shown in Figure 2. The most influential parameters are costs for peritoneal dialysis, costs and transition probabilities for kidney transplantation beyond 25 months after engraftment and QALYs. The

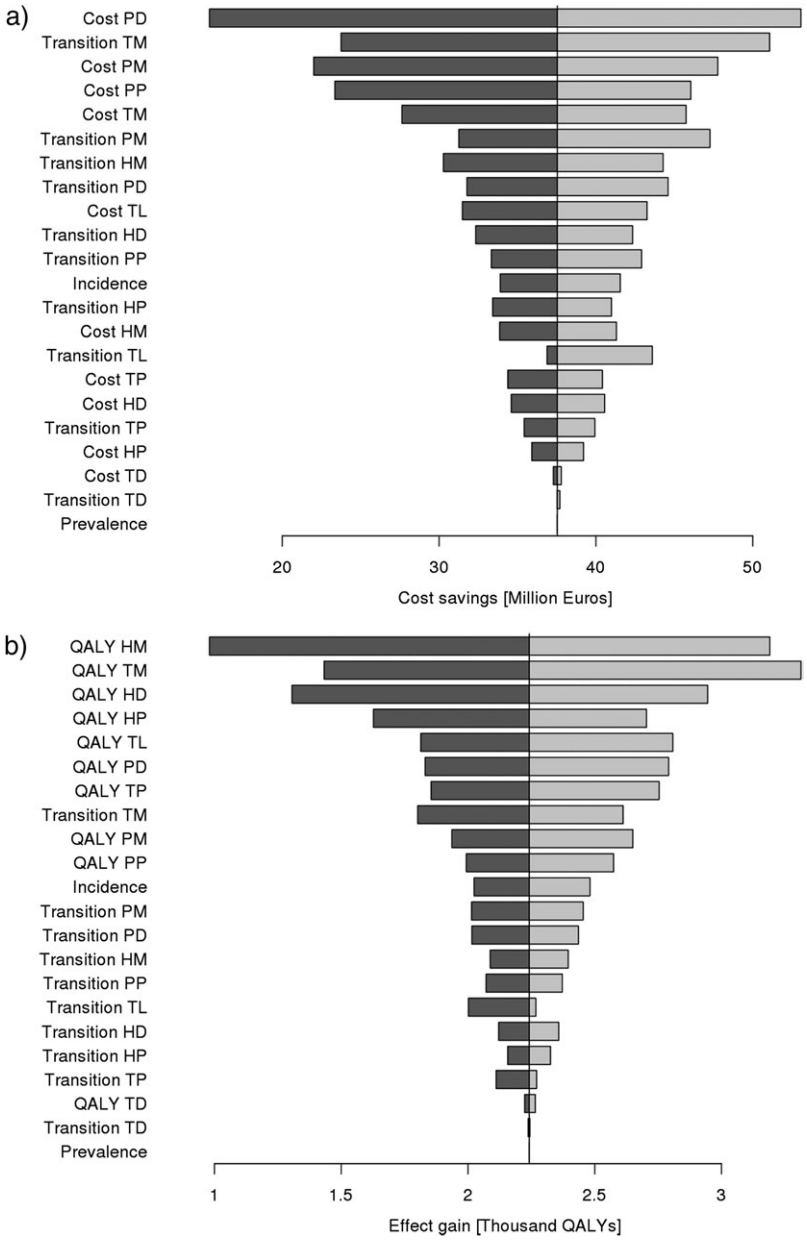

Fig. 3. Tornado sensitivity analysis for the policy of increasing PD assignment to 20% and TL to 10%. For costs, QALYs, prevalences and incidence rate, the horizontal bars show resulting ranges of discounted savings (in million Euros) and discounted gains (in thousand QALYs) when these model parameters are varied over their 95% confidence intervals shown in Tables 2 and 3 (annual discount rate 3%). Transition probabilities are grouped depending on the origin state and the horizontal bars show the resulting ranges when probabilities are varied over the respective 95% confidence regions (see Table 3). Horizontal bars are displayed top-to-bottom in decreasing order of length. The vertical lines represent the estimated saving and gains from the main model (see Table 4).

incidence rate is an influential parameter too. However, the sensitivity analysis predicts that even under the worst parameter configuration, Strategy 3 saves >€15 million and gains >1000 QALYs over the next 10 years after discounting.

Discussion

Our cost-effectiveness study showed that kidney transplantation and peritoneal dialysis perform better when compared to haemodialysis. Strategy 2 (20% peritoneal dialysis) and Strategy 3 (20% peritoneal dialysis and 10% kidney transplantation) can save €26 million and €38 million discounted respectively and gain 839 QALYs and 2242 QALYs respectively over the next 10 years when compared to Strategy 1 (haemodialysis dominated). We presented a Markov model based on individual cost data from the electronic patient records not only from the hospital administration but also from the social security insurance covering the total health care costs for each patient.

Our findings are consistent with those of others in regard to hospital haemodialysis being the least cost-effective treatment option for patients with terminal kidney failure [16, 17]. Peritoneal dialysis and kidney transplantation represent more cost-effective therapy strategies [2, 3, 15, 16]. Howard *et al.* [17] recently published a Markov model with similar results to our study on the cost effectiveness of RRT from the health care funder perspective in Australia and found a tremendous increase in QALYs and costs saved by increasing transplants and switching patients from hospital haemodialysis to peritoneal dialysis.

Despite the strengths of the present study in regard to individual costs for each patient covering all health care expenditures for the provision of ESRD treatment, there are certain limitations. Our study may potentially be biased by quoting values for quality of life from a Dutch study that was published in 1998 [16]. Like others, we had to estimate costs of organ procurement from brain-dead donors due to unavailable data [17]. We estimated costs of deceased donor management in the ICU from the average costs of comparable ICU non-donor patients and received higher costs compared to Howard *et al.* [17] (€3100 versus €2100), who estimated the costs for organ harvesting from a deceased donor based on expert opinion.

A potential selection bias may represent the higher transplantation rate for patients on peritoneal dialysis. This fact likely reflects the general practice to rather consider younger, self-determined healthier individuals for peritoneal dialysis and leaving those in worse conditions and of older age to haemodialysis.

Potential consequences of our findings are that every patient progressing to uraemia needs to be checked for eligibility for transplantation. The majority of ESRD patients, however, will not have access to preemptive renal transplantation either due to lack of a suitable donor within their social network or a medical condition contraindicated for engraftment. Any of these patients moving on to dialysis should be offered the option of peritoneal dialysis. Nevertheless, after all, kidney transplantation is widely accepted as the optimum treatment for eligible patients and contraindications to engraftment, especially in regard to age limit of recipients, have been narrowed lately [1, 29, 30]. Our results emphasize this approach to extend kidney transplantation programmes devoting reasonable amounts of resources in recruiting potential donors of both sources.

Demographic changes indicate that not only the number of patients but also the proportion of elderly people experiencing chronic kidney failure will continue to increase while treatment options even for high-risk groups improve over time leading to increasing financial pressure on health care systems worldwide [31, 32]. Besides stagnating transplantation rates from cadaveric donors in Austria over the last years, living kidney transplantation programmes have been are continuously rising since the early 1990's but currently do not reach comparable high rates as in northern European countries [19, 33]. Austria's haemodialysis domination providing almost exceptionally hospital-based haemodialysis offers great potential for improved cost effectiveness in the treatment of chronic kidney failure by reducing hospital-based haemodialysis as a consequence of increasing peritoneal dialysis and kidney transplantation. Thus, this study demonstrates a more cost-effective approach to RRT and offers great potential for superior outcomes not only for the ESRD population but also for the whole society in Austria.

Conclusions

Our results show cost effectiveness of both virtual assignment policies with a higher percentage of kidney transplantation and/or peritoneal dialysis compared to the currently used allocation to renal replacement treatment modalities predominated by haemodialysis. In face of these findings, we conclude that serious efforts ought to be made to foster not only altruistic living kidney donation but also more effective recruitment of potential brain-dead donors on the one hand and promote peritoneal dialysis as a superior alternative to haemodialysis for eligible patients on the other.

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