

A retrospective and prospective study of the number of kidney transplants in 31 countries

C. Chevalier¹, J. M. Dupuy², M. Busson³, J. Hors⁴, and G. Foulon¹

¹ INSERM U13 Hôpital Claude Bernard, 10 Avenue de la Porte d'Aubervilliers, F-75944 Paris, France

² Institut Mérieux, 58 Avenue Leclerc, F-69342 Lyon, France

³ INSERM U93, ⁴ France-Transplant, Hôpital Saint-Louis, 2 Place du Docteur Fournier, F-75010 Paris, France

Abstract. The aim of the present study was to try to predict the number of cadaveric kidney transplantations (CKT) that will be performed in the year 1993. The raw data regarding the number of renal transplants that have been performed annually since 1975 in 31 countries, which were divided into six groups, were collected from published reports and confirmed by a questionnaire sent to all centers. The annual number of grafts was estimated using an exponential model, highly correlated with retrospective data ($r^2 > 0.99$). Predictions for 1993 were extrapolated. The growth of transplantation activity is limited by a shortage of available donor organs. The maximum number of grafts was arbitrarily set at 40 per million population, which is the maximum rate currently observed. The total number of CKT carried out between 1975 and 1986 was 114000; this will probably exceed 280000 in 1993. The yearly activity in 1987 exceeded 16500 and is expected to reach approximately 26000 grafts in 1993.

Key words: Kidney transplantation, world wide trend - Kidney transplantation, predictions.

The impact of kidney transplantation on public health has markedly increased since the early 1980s and this procedure is now routinely carried out in more than 50 countries.

The aim of the present study was to try to predict the number of kidney transplantations that will be performed in 1993 in 31 countries with a combined population of 883 million inhabitants.

Data on the number of both cadaver kidney transplants (CKT) and kidney transplants from liv-

ing related donors (LRD) performed each year were collected for the period 1975-1986 in 31 countries. The trend of CKT was adjusted using an exponential model and the predicted figures were extrapolated until 1993.

Methods

Sources of data

The data collected consisted of the number of kidney transplantations performed yearly in 31 countries between 1975 and 1986. Information was provided from published reports and from national and international registries [1-6, 8-16].

In addition, a questionnaire was sent to all transplant centers and histocompatibility laboratories in order to confirm the data obtained. For six countries - Algeria, Egypt, German Democratic Republic, Hungary, Poland, and Tunisia - these data were taken from EDTA reports [13].

Data analysis for each country

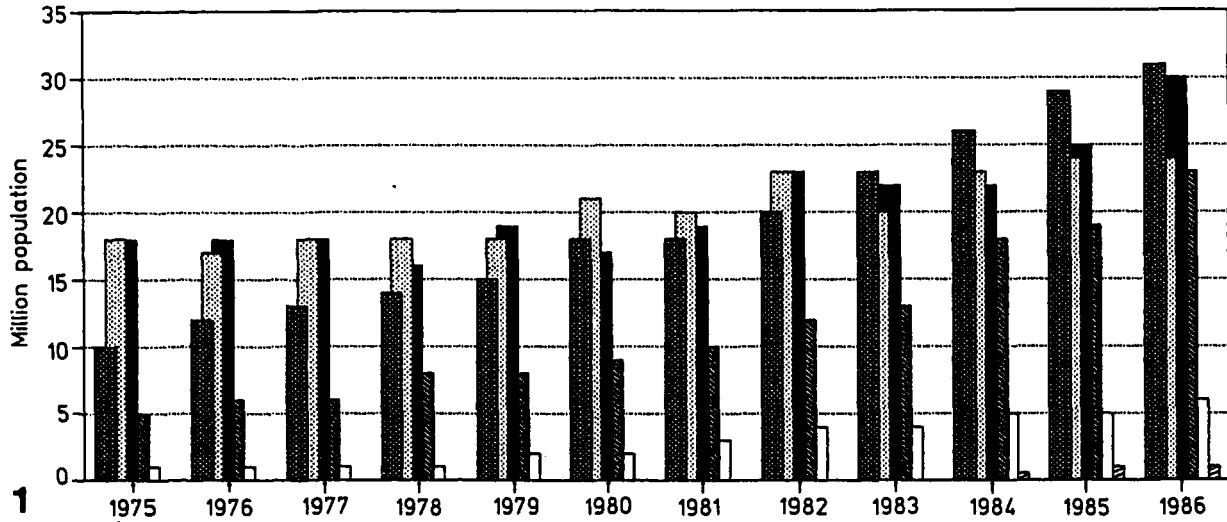
Regression analyses [7] were performed in order to find a suitable mathematical model (exponential model, simple quadratic fitting, or polynomial fitting) to describe the subsequent growth of CKT activity in each country. The exponential model was chosen because it gave the best correlation coefficients.

The following formula was applied for the data of each country:

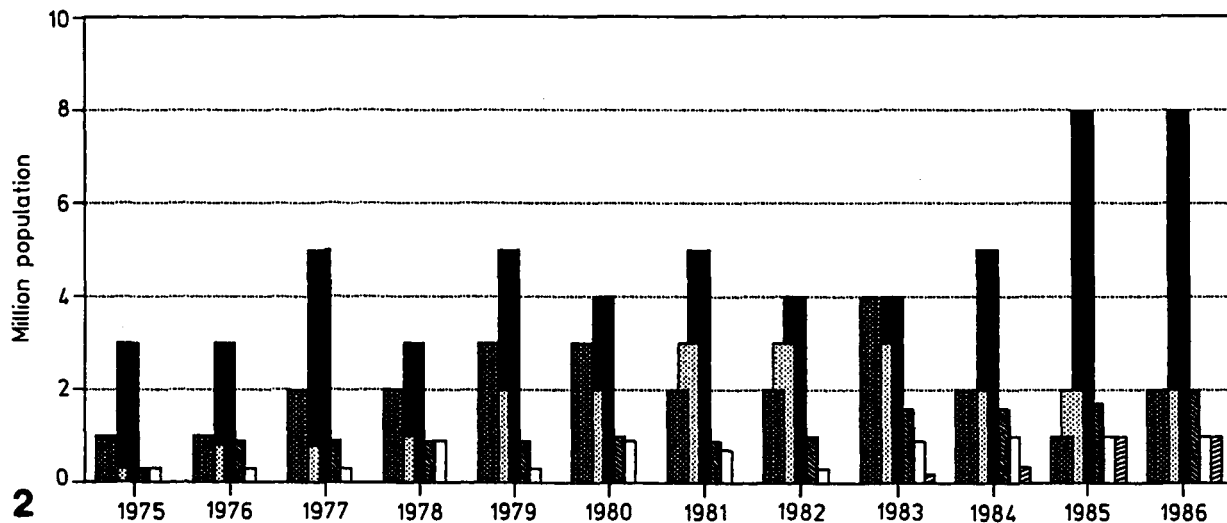
$$y = \exp(at + b)$$

where y is the logarithm of the estimated number of CKT per country, a is the growth of transplantation activity during the study period, t is the number of years since January 1975, and b is the logarithm of the estimated number of CKT performed in 1975.

When numbers of transplantations performed in the past were missing, values were estimated. (These are given within parentheses in Tables 1 and 2.) A comparison between the observed and calculated values for 1987 was done in order to assess the effectiveness of the method.



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Fig. 1. Evolution of the rate of cadaver kidney transplants per million population and per country group. ■, North America; ▨, Australia; ■, Europe I; ▨, Europe II; □, Europe III; ▨, North Africa

Fig. 2. Evolution of the rate of living related kidney transplants per million population and per country group. Symbols as for Fig. 1

Europe I (Scandinavia). Denmark, Finland, Norway, Sweden (23 million)

Europe II. Austria, Belgium, Federal Republic of Germany, France, Ireland, Netherlands, Spain, Switzerland, United Kingdom (255 million)

Europe III. Czechoslovakia, German Democratic Republic, Greece, Hungary, Israel, Italy, Luxemburg, Poland, Portugal, Turkey, Yugoslavia (216 million)

North Africa. Algeria, Egypt, Morocco, Tunisia (108 million)

Heterogeneity

The data analysis revealed considerable differences between countries. It was necessary to cluster the countries into six groups, taking three parameters into account: geographical location, rate of growth, and number of grafts per million population. On the basis of the latter parameter, the European countries were divided into three different groups, as indicated below:

North America. Canada, United States (total population: 265 million)

Australia. (16 million)

Predictive model

Middle-term predictions were made on the total number of grafts performed with cadaver donors in each group of countries. Predicted values were obtained by extrapolation of the curves fitted to data until 1993.

Two possibilities of further growth were considered: continuous growth until 1993 and growth limited by the availability of organs (40 grafts per million population). This upper limit was deliberately fixed at the highest rate already performed, namely, that in Denmark [14].

Table 1. Cadaver kidney transplants by country group performed yearly since 1975 (observed and estimated values^a)

Country	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total	Rate ^b
Canada	(248)	(338)	(285)	(305)	(327)	(350)	408	424	544	586	634	673	5122	28
United States	(2585)	(2834)	(3108)	(3408)	3736	4427	4400	4770	5517	6272	7169	7699	55925	32
Total North America	2833	3172	3393	3713	4063	4777	4808	5194	6061	6858	7803	8372	61047	31
Australia	286	270	296	287	282	350	324	363	314	374	378	395	3919	24
Denmark	111	100	(107)	(108)	121	98	102	132	105	111	125	208	1428	42
Finland	71	98	(93)	(101)	104	115	128	126	130	89	84	128	1267	32
Norway	78	59	68	69	63	53	79	74	99	101	98	89	930	23
Sweden	143	124	(136)	(147)	157	134	133	195	180	202	274	285	2110	36
Total Europe I	403	381	404	425	445	400	445	527	514	503	581	710	5735	30
Austria	84	51	(57)	(240)	62	70	55	71	147	150	158	177	1322	23
Belgium	84	73	(95)	(102)	110	180	132	116	141	144	165	253	1595	26
France	308	407	410	525	552	602	640	759	804	861	1027	1246	8141	22
FRG	145	(158)	(194)	(240)	244	365	400	462	(522)	971	1151	1235	6087	21
Ireland	18	(20)	(22)	(25)	22	40	34	58	52	38	63	92	484	23
Netherlands	116	130	(141)	(154)	194	128	250	233	278	316	241	297	2478	22
Spain	16	(27)	(28)	(56)	75	120	203	331	321	671	662	848	3358	22
Switzerland	103	(86)	(103)	(108)	100	144	131	163	105	161	177	190	1571	32
United Kingdom	570	498	(605)	(658)	788	747	827	813	971	1212	1208	1503	10400	27
Total Europe II	1444	1450	1655	2108	2147	2396	2672	3006	3341	4524	4852	5841	35436	23
Czechoslovakia	38	46	(50)	(55)	81	58	70	86	83	129	(141)	(156)	993	11
GDR	48	(60)	(71)	(84)	126	106	116	190	172	173	(204)	156	1434	9
Greece	-	-	-	1	1	1	2	2	6	9	25	27	74	2
Hungary	6	(7)	(9)	(12)	11	25	26	27	40	(46)	(54)	(47)	310	4
Israel	11	14	19	4	37	40	69	109	76	62	61	69	572	17
Italy	97	(105)	(121)	(136)	123	137	226	303	214	415	372	236	2485	5
Luxemburg	-	-	-	-	-	-	1	-	2	3	2	2	10	4
Poland	9	(14)	(17)	(21)	45	27	47	40	48	144	(167)	276	905	9
Portugal	-	-	-	-	-	8	26	30	66	63	99	104	396	10
Turkey	-	-	-	-	2	9	0	2	7	40	16	11	87	1
Yugoslavia	14	(14)	(15)	(16)	21	15	12	15	16	19	19	72	248	3
Total Europe III	223	260	302	329	447	426	595	804	730	1103	1160	1156	7514	6
Algeria	-	-	-	-	-	-	-	-	-	-	1	0	1	1
Egypt	-	-	-	-	-	-	1	0	0	0	0	0	1	1
Morocco	-	-	-	-	-	-	-	-	-	6	6	0	12	1
Tunisia	-	-	-	-	-	-	-	-	-	5	5	4	14	1
Total North Africa	-	-	-	-	-	-	1	0	0	11	12	4	28	1
Total	5189	5533	6050	6863	7384	8349	8843	9894	10960	13373	14786	16478	113679	19

^a Estimated values for missing data are given within parentheses

^b Rate of grafts performed in 1986 per million population

In the North African group of countries, the short follow-up of transplantation activity makes a statistical evaluation difficult. It was therefore decided to use a 30% hypothesis for growth during the forthcoming 5 years.

Results

Analysis of the evolution of CKT per country group since 1975

Figure 1 depicts the trend in the rate of CKT per million population and per group since 1975; the raw data are presented in Table 1.

North America. In 1975, Canada and the United States had considerable CKT activity: 2833 transplantations, or 11 transplantations per million popu-

lation. The annual number of transplantations increased by 200% in 11 years to 8372 in 1986, i.e., 31 transplantations per million population. Thus, between 1975 and 1986, North America accounted for more than half of the CKT performed in the six groups of countries combined.

Australia. In 1975, the rate of CKT was 18 per million population (286 transplants in a total population of 16 million). Between 1975 and 1986, the growth rate was 30%, bringing the rate up to 25 per million population (395 transplants) in 1986.

Europe I. In 1975, the rate was 18 transplantations per million population (403 transplants in a population of 23 million). Growth between 1975 and 1986

Table 2. Kidney transplants with living related donors by country group performed yearly since 1975 (observed and estimated values^a)

Country	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total
Canada	(43)	(48)	(52)	(63)	(69)	(73)	74	77	105	76	103	105	888
United States	(300)	(350)	(400)	(500)	(600)	634	(500)	492	935	(500)	(350)	308	5869
Total North America	343	398	452	563	669	707	574	569	1040	576	453	413	6757
Australia	5	12	11	17	34	32	36	52	50	46	34	33	362
Denmark	(15)	26	0	4	5	2	2	3	6	5	19	(25)	112
Finland	(20)	18	14	12	15	5	11	16	3	6	18	15	153
Norway	34	23	32	31	32	34	43	32	45	54	81	82	523
Sweden	(7)	9	68	28	58	43	55	52	53	76	67	62	578
Total Europe I	76	76	114	75	110	84	111	103	107	141	185	184	1366
Austria	10	35	4	7	3	2	2	3	15	1	8	9	98
Belgium	1	9	14	16	15	78	12	9	31	52	55	38	330
France	32	49	26	46	26	64	68	98	102	110	114	144	879
FRG	10	57	64	122	13	9	11	16	35	12	42	53	344
Ireland	7	8	0	5	11	12	5	24	10	11	19	8	120
Netherlands	(2)	3	18	30	3	3	10	24	31	29	43	46	242
Spain	9	8	(22)	9	24	26	28	41	46	16	(29)	23	281
Switzerland	(12)	(18)	26	25	91	1	3	4	61	52	36	48	377
United Kingdom	13	29	85	70	41	114	117	117	114	170	122	148	1140
Total Europe II	96	216	259	230	227	309	256	336	445	453	465	517	3811
Czechoslovakia	-	-	-	-	1	2	2	1	1	1	5	7	20
GDR	-	-	-	-	1	(7)	(10)	(16)	(24)	(30)	(36)	(42)	166
Greece	14	3	3	13	4	14	14	12	21	28	18	27	171
Hungary	3	(3)	(3)	(3)	3	3	1	0	2	1	(2)	(3)	27
Israel	6	10	12	28	11	34	5	12	22	16	27	21	204
Italy	(42)	48	40	92	25	5	17	22	17	20	41	14	383
Luxemburg	-	-	-	-	-	-	-	-	-	-	-	1	1
Poland	-	-	-	-	-	-	-	-	1	1	1	2	5
Portugal	2	0	0	0	1	1	1	1	1	(2)	(3)	(4)	16
Turkey	-	-	-	-	11	41	(30)	25	40	107	134	(48)	499
Yugoslavia	(16)	(18)	20	0	0	8	3	16	26	47	41	65	260
Total Europe III	83	82	78	136	57	115	83	105	155	254	309	296	1753
Algeria	-	-	-	-	-	-	-	-	-	-	-	2	2
Egypt	-	-	-	-	-	-	-	-	-	9	37	72	118
Morocco	-	-	-	-	-	-	-	-	-	-	-	1	1
Tunisia	-	-	-	-	-	-	-	-	-	-	-	5	5
Total North Africa	-	-	-	-	-	-	-	-	-	9	37	80	126
Total	603	784	914	1021	1097	1247	1060	1165	1797	1479	1483	1523	14175

^a Estimated values for missing data are given within parentheses

amounted to 68%. In 1986, the Scandinavian countries nearly reached the rate of 30 CKT per million population.

Europe II. In this group, a mean of 5 CKT per million population were performed in 1975. Between 1975 and 1986 the growth rate was nearly 500%. This group reached a rate of 23 transplantations per million population in 1986, one-third of the total number of grafts included in this study. Growth was highest in the Federal Republic of Germany, where the number of transplantations increased fivefold between 1975 and 1983. Since 1983, growth has been the most rapid in the United Kingdom (from 971 transplantations to 1503) and in Spain (from 321 to 848 transplantations).

Europe III. In 1975, transplantation activity in this group of countries was equivalent to about 3% of

the total number of CKT performed in all 31 countries. In spite of a growth rate of 388% during the study period, the rate of 6 CKT per million population that was observed in 1986 was lower than that observed in 1975 in most of the other groups.

North Africa. In 1986, transplantation activity represented only 1% of the overall CKT activity (4/16478) in all 31 countries.

Analysis of the evolution of living related kidney transplantation per country group since 1975

Figure 2 shows the trend in the rate of kidney transplants using living related donors per million population in each group since 1975. The raw data are presented in Table 2.

Including all data, the proportion of kidneys transplanted with LRD represented around 10% of the total activity (1523 transplants) in 1986. The Scandinavian countries (Europe I) had a significantly higher percentage of LRD grafts.

Effectiveness of the model

Results of the regression analysis are presented in Table 3. The parameters of the model (intercepts and slopes) are given, as well as the growth rates per group of countries for the period of time 1975-1993, the initial values in 1975, and the correlation coefficients. The correlation value for the total interval of time ranges from 0.85 for Europe I (Scandinavia) and Australia to 0.99 for North America.

Table 4 displays the observed values of CKT in three groups of countries in 1987 compared to the predicted values obtained by the model.

In order to check the accuracy of the predicted values, the resulting adjusted data were compared with those reported in national registries for the year 1987, i.e., Scandia-Transplant, Australian New Zealand Data Transplantation Association (ANZDATA), and European Dialysis Transplantation Association (EDTA). Comparisons between calculated values and reported data did not show any statistically significant differences.

Predictions for 1993

Table 5 shows the trend in CKT activities in the middle term. In 1993, it is expected that the total values will reach approximately 277 748 transplants, with an upper limit of 40 grafts per million population (304 719 if no upper limit is applied). Assuming there is a stable shortage of organs, North America, Europe I, and Europe II will have supply difficulties in 1993; the growth of activity in Europe III and North Africa will not yet have reached their maximum levels.

As for the LRD grafts, after doubling in rate between 1975 (603) and 1986 (1523), activity remained stable for 3 consecutive years (Table 2). No predictions were made for this category of grafts.

Discussion

The trend in the number of CKT performed in 31 countries from 1975 to 1993 is described using a mathematical model based upon a statistical analysis. The model fits the observed data with a high

Table 3. Results of regression analysis over the period 1975-1986. Estimates of the model coefficients and the correlation coefficients for each country group

Country Group	Annual growth ratio	Initial estimated value in 1975	R ^{2a}
North America	1.12	2149	0.99
Australia	1.029	270	0.85
Europe I	1.05	398	0.85
Europe II	1.13	1316	0.98
Europe III	1.16	219	0.96
North Africa	-	-	-

Estimated and predicted values were obtained using the equation. $Y = \exp(at + b) = \exp(at) * \exp(b) = \exp(a)^t * \exp(b)$

^a Proportion of variances explained by the regression

Table 4. Comparison between the observed values in 1987 and the values predicted using the model for CKT activity. (Differences not statistically significant)

Country	Predicted values	Observed values	Confidence interval
Europe I	750	701	510- 765
Australia	391	368	338- 474
Europe II	6645	7075	5341-7452

Table 5. Number of cadaver kidney transplants (CKT) expected to be performed in 1993 and total number carried out since 1975

Country group	Number of grafts ^{a,b}		
	In 1993	Since 1975	Per million population
North America	10640 (18 508)	134 125 (155 649)	40 (70)
Australia	437 (437)	6 730 (6 730)	27 (27)
Europe I	920 (957)	11 515 (11 551)	40 (42)
Europe II	10 200 (13 742)	99 479 (104 254)	40 (51)
Europe III	3 860 (3 860)	25 916 (25 598)	18 (18)
North Africa	75 (75)	301 (301)	3 (3)
Total	26 132 (37 519)	277 748 (304 719)	29 (42)

^a Numbers without parentheses indicate an upper limit of 40 grafts per million population

^b Numbers within parentheses indicate no upper limit

degree of correlation ($0.85 < r^2 < 0.99$). It was validated for the year 1987 and showed no significant differences between calculated values and reported data.

In the countries studied, the model predicts that 26 000 CKT will be performed in 1993. Kidney transplants from living related donors - approximately

1000–2000 per year – should be added to this number.

Growth in CKT activity is expected to remain stable: around 12%–13% in North America and Europe II, 5% in Europe I, and 3% in Australia. These countries will reach their maximum level in the early 1990s. In Europe III, the prospects are less limited. This group of countries could meet the demand within the next 10 years. The highest potential growth in CKT activity is expected in North Africa, where the demographic growth rate is considerable.

These results could be questioned since they depend on maximum organ availability. Two scenarios were therefore presented, one with a growth rate limited to 40 grafts per million population and one without any limits. However, many factors can influence this limit, including, organ preservation, and sociolegal measures.

Our model also predicts that the percentage of CKT will probably remain lower than the rate of end-stage renal disease (ESRD) in all countries. Even if the rate of CKT would exceed 40 per million population, the demand would probably still exceed the supply, in the middle term, for two reasons. Firstly, an increasing number of retransplantations will be performed, thus increasing the shortage of transplantable organs. Secondly, an increase in demand can be expected, due to a broader definition of ESRD and to a rise in the upper age limit of patients.

It is obvious that a variety of parameters, such as availability of organs and success rate of grafts, may greatly influence the trend in kidney transplantation. None of these were taken into account in the present study. More studies are needed to further validate our model. Nevertheless, it is extremely important to compile all available data on the number of transplants performed in order to gain insight into the overall activity, in other countries as well, and to evaluate the trends.

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