Further Applications of a Statistical Approach to Haemodialysis and Transplantation Programmes

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Now that intermittent haemodialysis has become an accepted form of therapy for patients with chronic renal failure, there is an urgent need to define the facilities required by hospitals supporting such programmes. The unit at The London Hospital opened three years ago and combines hospital and home dialysis with transplantation (Dathan et al., 1970). Amongst other criteria for the selection of patients we insist that they should be capable of managing home dialysis, and it is only when this has been successfully established that we consider them for transplantation.

Over a year ago we were approached by the hospital authorities and asked for a five year assessment of our unit, with special regard to bed and financial commitments. We have recently published a mathematical approach to this problem (Farrow et al., 1971) which is based on the Markov Chain principle (Kemeny & Snell, 1960; Lu, 1968). This system relies upon defining a series of states through which any patient may pass, and, of necessity, these must cover any situation or sequence of events which may befall him during the course of his time in the programme. The model covering events in our own unit incorporates 26 states and each of these is based on a time unit of one month. In this, every patient has a certain probability each month of remaining in the same state, moving to the next relevant one — or dying. By priming the 26 states with the relevant sets of probability figures it was possible to form a matrix of all possible transitions incorporating these results (Figure 1). A computer was now used to carry out a process of matrix multiplication and this produced figures for the number of patients to be found in any of the states at any given number of months in the future.

We have only examined a five year period as changes in transplant and dialysis survival may well make predictions beyond this time invalid. Allowance has had to be made for variations in the number of new patients being accepted into the scheme each month, and also in the length of time spent waiting for a transplant. From this analysis we have been able to predict
Figure 1. This matrix covers all possible transitions between the various states with the probabilities of doing so shown within the reinforced squares. X and Y represent the range of probabilities which arise when the wait for a transplant whilst at home on dialysis is varied between 1-6 months.

numbers of patients in the dialysis unit, on home dialysis, and those in the transplant group, as well as providing further information on transplantation rates and overall costs. We have analysed the length of stay and numbers of hospital readmissions of our present quota of patients over the past year, and from this have predicted the number of supporting medical beds required by our programme over the next five years. The purpose of this communication is to demonstrate two further applications of this particular statistical approach. The first involves a direct comparison between units having different facilities for treating end stage renal failure. The second analyses the possible increase in laboratory facilities required by a unit employing both home dialysis and transplantation, allowing for the expected increase in patients over the next five years.

COMPARISON OF DIALYSIS PROGRAMMES
One interesting application of the Markov Chain approach is that if the resulting matrix of probabilities is multiplied enough times the system will eventually
reach a steady state. At this point numbers of patients on hospital and home dialysis as well as transplant recipients remain constant, and deaths will cancel out the input rates into the separate categories. Although changes in survival figures, as well as other variables, will alter the position of the steady state, this theoretical approach has enabled us to compare the three different types of system.

These are, firstly, units employing hospital and home dialysis with no access to transplantation; secondly, units employing hospital dialysis with access only to transplantation and, thirdly, those employing all three forms of treatment. We primed each system with identical, and currently acceptable, survival probabilities and by using a standard intake of one new patient per month into each, multiplied the resulting matrices until a steady state was reached. We used a dialysis survival of 0.99 (0.99 represents the probability of surviving one month and is equivalent to a two year survival of 79% of patients on dialysis) and a transplant graft survival of 0.98 (giving a 2 year survival of 40%).

Figure 2. A comparison of the three models when each has reached the 'steady state' (see text). The distribution of patients has been expressed in percentages.

Figure 2 shows the distribution of patients in each of the three systems when a steady state has been achieved. The top line shows a centre employing hospital and home dialysis only. Eleven per cent of patients are undergoing unit dialysis and 89% home dialysis. Although the hospital unit will be treating reasonable numbers of patients the home dialysis commitment is extremely large and because of this will provide a very expensive undertaking for the hospital concerned. We have already seen an example of this in Great Britain. The second line shows a hospital unit with access only to transplantation. Sixty-two per cent of the patients will be found in the hospital unit and, unless the unit is to be unusually large, this will significantly limit the total number of patients that can be treated. In the bottom line, the system employ-
ing all three forms of treatment, only 14% of patients are found in the hospital unit and there are manageable commitments to both home dialysis (48%) and transplantation (38%).

It would therefore seem reasonable to conclude that centres employing hospital and home dialysis as well as transplantation will be able to treat more patients on a long-term basis if either the size of the dialysis unit or the cost of home dialysis are to be limiting factors. This steady state analysis can also provide figures on overall numbers of patients in the three groups, as well as indicating differences in patient survival between the three systems. For these to be meaningful, however, very accurate data must be used to prime the systems, and, as yet, we do not believe these are available.

LABORATORY FACILITIES

The ancillary services play an important role in supporting dialysis programmes. We first examined the demands placed on the clinical laboratories with regard to the specialities of haematology, bacteriology and biochemistry. Because of difficulties in data collection we have only been able to assess this so far in our own unit. The first step was to obtain a five year projection of our own unit in terms of numbers of patients being treated, and to determine the distributions between unit and home dialysis, and transplantation. This was done by multiplying our original matrix of transition probabilities for a

![Graph showing patient numbers over years for dialysis/transplant programme.](image)

Figure 3. The shaded area demonstrates the five year projection of the London Hospital unit with an intake of three new patients per month. The dotted lines indicate how the system may eventually reach a 'steady state' providing that survival probabilities and other factors remain constant.

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period of sixty months and the results are shown in Figure 3. This also shows, incidentally, theoretical projections demonstrating how our own unit might eventually reach the steady state if we took on an average of three patients per month over this period. Within the five year projection it is important to note the relatively large increase in the transplanted section when compared to those on haemodialysis.

We also analysed the investigations performed each month on all of our patients from March 1970 until March 1971, and these were separated into haematological, bacteriological and biochemical. The term investigation is used to refer to separate laboratory procedures — even if these only involved preparing different blood samples for the auto-analyser, and not individual specimens from each patient. The most common haematological investigations performed were the haemoglobin and haematocrit, the differential white cell count, a platelet count and erythrocyte sedimentation rate. These all counted as separate procedures. Less common investigations included coagulation and iron studies, grouping and cross-matching of blood, and vitamin B₁₂ and folate estimations. The majority of bacteriological investigations involved plating specimens for culture. With regard to biochemistry all our dialysis patients have a monthly screen in addition to any further investigations thought necessary because of medical complications. The monthly screen has been taken as involving nine separate procedures and this is probably an underestimation of the problem. On blood samples determinations are made on the levels of alkaline phosphatase, serum glutamic oxaloacetic transaminase, uric acid, urea and electrolytes, calcium, magnesium, phosphate and total and differential protein levels. If the patients produce urine this is examined for electrolyte content.

With these definitions of the separate procedures we assessed the monthly average of investigations carried out on patients within the three categories of unit dialysis, home dialysis and transplantation. Figure 4 shows the average number of investigations carried out per month on these three categories of patients. It is interesting to note that investigations on transplanted patients reach fifteen per month for haematology, nearly seven for bacteriology and

<table>
<thead>
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<th>INVESTIGATIONS per MONTH</th>
<th>UNIT DIALYSIS</th>
<th>HOME DIALYSIS</th>
<th>TRANSPLANTS</th>
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<td>HAEMATOLOGY</td>
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<td>7.3</td>
<td>15.3</td>
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<tr>
<td>BACTERIOLOGY</td>
<td>3.4</td>
<td>4.0</td>
<td>6.7</td>
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<tr>
<td>BIOCHEMISTRY</td>
<td>13.5</td>
<td>12.3</td>
<td>24.3</td>
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Figure 4. The results are shown of a twelve month analysis of investigations carried out on all our patients and expressed as a monthly average.

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twenty for biochemistry. Furthermore, these figures average just about double those performed in either of the two dialysis groups. These results must be viewed in the knowledge that, as we are a new unit, our transplantation programme has a large proportion of recently transplanted patients when compared to long survivors. This will bias the figures to some extent. Units like ours anticipating large increases in the transplantation group must make suitable arrangements to expand their laboratory facilities.

Figure 5. Investigations per month in 1971 and anticipated workload per month in 1976 for haematology, bacteriology and biochemistry

Figure 5 shows the laboratory workload for 1971 in the lefthand columns and the anticipated workload for 1976 in the righthand columns. These have been obtained by combining the results of our five year projection (Figure 3) with the average number of monthly investigations for each patient (Figure 4). At present we perform approximately 500 haematological investigations per month; in 1976 we can expect anything up to 1700. In bacteriology the figures are 200 and 750 respectively. The biochemical laboratories perform 800 investigations per month at present and this represents nearly 20% of the monthly total biochemical workload performed in the hospital. In 1976 we expect this
to rise to 2700 per month. Advances in automation will help to some extent in the fields of both haematology and biochemistry, but we suspect that much of the bacteriology will have to be done by hand.

In conclusion, we have presented a system of analysis which, suitably primed, will provide a great deal of information useful in the planning of both dialysis and transplantation programmes. I would again stress that the purpose of this paper has been to demonstrate the methodology of a particular statistical approach. We do not feel that as yet we have enough data to supply authoritative results.

We should like to end on a rather contentious note. Renal units in Great Britain last year were requested to fill in detailed questionnaires on all our patients for the EDTA survey, The Ministry of Health, The Transplant Registry and The Combined Colleges Committee. In addition, we provided detailed information used in replies to parliamentary questions on two occasions. We suggest that only one questionnaire is filled in each year by individual units and that the information should be fed into data banks organised on a national or European scale. Interested parties such as the EDTA, Ministries of Health and even individual units would have immediate access to this information. At the moment the presentation of data from most of these bodies is such that it is difficult, if not impossible, to perform any useful analysis of their results. If data were now analysed using an approach similar to the one we have described, the extent of the problem of the long term treatment of renal failure could be more objectively assessed not only on a national, but also on an international level and cooperative projects in Europe, especially in relation to renal transplantation, could be more readily advanced.

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REFERENCES

OPEN DISCUSSION

J MOORHEAD (London): Does the steady state situation not depend very much on the rate at which you are doing transplantation? In other words, what is the transplant waiting time in this model?

FISHER: Yes, Dr Moorhead, of course you are absolutely right. The problem is in working out how long patients have to wait for transplantation. This is why we feel that you should use it as a retrospective analysis and update your results each year. We, in our unit, find that our patients wait an average of four months after they have started home dialysis before they receive a transplant. Of course, this may well vary and we should like to think that as there is greater European cooperation with an increase in recipient pool size, and perhaps increasing availability of donor kidneys, this will be cut down. But I think that this must be a retrospective analysis to be accurate in the first instance. I think that you have raised a valid point.