Simulation models in the planning of health care facilities: an application in the case of neonatal extracorporeal membrane oxygenation

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Objectives: To investigate whether modelling techniques can be used in the planning of health care facilities for patients requiring neonatal extracorporeal membrane oxygenation (ECMO).

Methods: In a micro-simulation model the number of patients that will have to be referred to facilities abroad is estimated for any number of neonatal ECMO patients presenting annually for treatment in The Netherlands, and any number of ECMO facilities. The inputs to the model consist of the number of ECMO facilities, the number of patients presenting annually, the duration of treatment and the date on which patients present for ECMO treatment. The model is estimated on data from The Netherlands for 1992, during which 29 patients were treated in three facilities. Several future scenarios are modelled, principally one in which a potential increase to 56 patients per year is foreseen.

Results: The model indicates that, if such an increase takes place, no additional ECMO facilities will be necessary in The Netherlands if between three and four referrals annually to centres outside the region (or abroad) are considered acceptable and feasible. In that situation, it is expected that on 22 occasions each year two patients will be treated simultaneously, for a total of 81 days. On ten occasions, all three facilities will be occupied at the same time, for 21 days in total. On 199 days, at least one of the facilities will be occupied.

Conclusion: The current study shows that the acceptability and feasibility of patient referrals to ECMO centres abroad is an important issue which health care planners will have to consider. The study also shows that modelling techniques can provide information that is useful to policy-makers in the planning of health care facilities.

Introduction

Extracorporeal membrane oxygenation (ECMO) is one of the new technologies in neonatal intensive care. It is a device which is potentially life-saving for neonates with reversible respiratory diseases due to various causes. By temporarily taking over the function of the lungs and heart, ECMO can give diseased lungs the opportunity to recover and can avert the pulmonary complications that frequently occur if prolonged high-pressure ventilation is necessary. However, ECMO itself may induce complications, most notably bleeding due to systemic anticoagulant treatment. Therefore, ECMO treatment is generally limited to those who are thought to have a high risk of death with conservative treatment (a predicted survival of 20% or less) and a low risk of complications with ECMO (e.g. a birthweight of 2000 grams or more). For these patients, ECMO appears to be effective: the Extracorporeal Life Support Organisation (ELSO) reports an overall survival of 80% in 11 000 neonates treated with ECMO, and recently, in the UK, the first large prospective randomised controlled trial on ECMO was stopped by the data monitoring committee because patients in the ECMO group showed a much better survival rate than those treated with intensive conservative therapy. Reports on the quality of life after ECMO so far are also favourable. Even though a recently published long-term follow-up study did indicate that ECMO survivors may have an increased risk of behavioural problems and academic difficulties at the age of 5 years compared to patients surviving after conservative treatment, in general, equal or less neurological and psychomotor dysfunction is reported for ECMO survivors than for those managed conservatively.
Neonatal ECMO has been introduced differently in various countries. In the USA, ECMO is already an accepted form of therapy for high-risk neonates. In Europe, the introduction of ECMO is on-going. Since 1987, ECMO centres have been founded in Germany, France and Sweden among others. In the UK, ECMO was introduced in the context of a randomised controlled trial. In The Netherlands, the attitude towards neonatal ECMO has also been cautious. Up to 1995, there were three centres in operation, all waiting for a definite decision on their future status by the health care authorities.

Once the health care authorities in a country approve the use of ECMO, they also have to decide on the number of ECMO facilities that are necessary to provide adequate care. Additionally, in a region where ECMO is already an established therapy it may be necessary to adjust the number of ECMO facilities if changes in the indications for this treatment occur. It is to be expected that the required number of facilities in a region will depend on the number of patients who fulfill the indications for ECMO, the average duration of ECMO treatment and the occurrence of simultaneous patient presentation. Therefore, for any given number of ECMO facilities, momentary over- or under-capacity may occur. Since ECMO is a potentially life-saving treatment, patients who cannot be treated at moments of under-capacity will either have to be treated conservatively – with almost certainly a lower survival probability – or be referred to ECMO centres elsewhere. Whether or not such referrals are feasible and desirable are questions that will not be addressed in this article. Here, we concentrate on the consequences of the establishment of various numbers of ECMO facilities in The Netherlands. The approach followed is generally applicable to any region in any country with the same number of patients requiring ECMO treatment, similar indications and the same distribution of ECMO treatment durations. Additionally, if one of the above variables is different from the Dutch situation, the model can easily be adapted to the local situation.

**Methods**

**Model development**

The model describes a process of events after a seriously ill newborn child has been admitted to a Dutch hospital. If the child needs ECMO treatment, and if there are no contraindications, the availability of an ECMO facility is assessed. If an ECMO facility is available the child will be transferred to that facility, otherwise the child will be transferred to a facility abroad (Fig. 1).

In the model, the number of ECMO facilities required to treat various numbers of patients is estimated by simulating ECMO treatments for 1000 separate years and more than 1.8 million individual patients in a discrete event micro-simulation model (Figure 1). The micro-simulation model is based on four variables: the number of ECMO facilities; the number of patients presenting annually; the duration of treatment; and the day of the year patients present for ECMO treatment. First, a baseline analysis is performed, describing the situation in The Netherlands in 1992. Then, several alternative scenarios are formulated to study the effects of plausible future events on the number of ECMO facilities required. Finally, a sensitivity analysis for the main variable, duration of treatment, is performed.

**Model estimation**

The baseline analysis is based on real data for The Netherlands. In 1992, three ECMO centres were functioning in The Netherlands. Two centres, in Rotterdam and Nijmegen, included patients strictly according to a common research protocol, limiting treatment to neonatal patients with an AaDO2 above 600 mmHg for 8 hours, or an Oxygenation Index above 40 in three to five consecutive blood gas samples within 5 hours. Patients with serious heart disease, causing an important right to left shunting, were excluded. The third facility, in Maastricht, did not follow an official protocol. For this centre, data were only included on the five patients who would have fulfilled the entry criteria used by the other two centres. Patients treated between January 1991 and July 1993 were used for the estimation procedure. The main characteristics of these patients are described in Table 1.
The mean treatment duration for these patients was 6 days with a minimum of 0.6 days and a maximum of 15 days. For the model the actual distribution of these times was used to simulate the duration of treatment for each patient. Four hours were added to the duration of treatment, representing the minimum period necessary for cleaning and priming the equipment. Patients were said to be treated simultaneously if any part of their treatment period, including the cleaning period, overlapped with the same period of any other patient.

For each patient the model simulated the date of birth according to the monthly distribution of births in The Netherlands in 1992. Here the assumption was made that ECMO indications themselves showed no separate seasonal trend. As a matter of convenience, the date of birth was used as an approximation of the day of presentation for treatment, because patients were treated with ECMO within an average of 1.9 days (range 0-15 days) after birth.

Results

In the baseline analysis, 29 patients per year are treated in three facilities, as was the situation in The Netherlands in 1992. The model shows that the three facilities will on average be occupied for 58 days per year if patients are evenly spread over the facilities. The other results from the simulations are summarised in the first three columns of Table 2. The estimates based on the micro-simulation model differ slightly from the observed figures, which are shown in the fourth column, but all observed figures fall within the minimum-maximum range of the results estimated by the model. However, caution should be taken in comparing the estimates with the observed figures because no record was kept of the referrals to centres abroad.

Alternative scenarios

Because ECMO was a new medical treatment facility in The Netherlands, referral policy for this treatment was probably still suboptimal in 1992. Also, it can be expected that inclusion criteria will widen and contraindications will narrow with time. Therefore, the number of treatments per year will probably rise. If the 29 treatments in 1992 are related to the 196 734 live births that year, one ECMO treatment per 6784 live births was performed. Estimates based on the ELSO registry tend to a higher rate of ECMO treatments: one in 3859 live births in 1988. Investigators in Georgia, Michigan and Oregon/Washington estimated the need for ECMO in the same magnitude: one in 3717, one in 3431 and one in 3521 births respectively. The need for ECMO in the UK has been estimated at approximately one in 5000 live births.

If these estimates apply to the Dutch situation – after the treatment has become current practice – the number of treatments will rise to 39 (one in 5000 live births) or maybe even to 56 (one in 3500 live births) per year, and, of course, the number of ECMO facilities will have to be adapted to this new situation. In the alternative scenarios account is taken of these changes.

The separate scenarios simulate the effects of a change in the number of neonatal patients annually presenting for treatment, or a change in the number of facilities, or both. It is assumed that there is no change in the average duration of treatment or in the distribution of treatment durations. As may be expected, the number of occasions on which patients require treatment at the same time increases with the number of patients presenting per year.

### Table 2 Results of the simulation model predicted for 1992 compared to the observed events in 1992, and several alternative scenarios

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1992 situation</th>
<th>Alternative scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29 patients</td>
<td>56 patients</td>
</tr>
<tr>
<td></td>
<td>3 facilities</td>
<td>4 facilities</td>
</tr>
<tr>
<td>Patients referred for treatment abroad</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>0.2</td>
<td>3.5</td>
</tr>
<tr>
<td>min</td>
<td>0</td>
<td>4.8</td>
</tr>
<tr>
<td>max</td>
<td>2</td>
<td>13.7</td>
</tr>
<tr>
<td>obs</td>
<td>NA</td>
<td>137.5</td>
</tr>
<tr>
<td>Days at least 1 patient is treated</td>
<td>137.5</td>
<td>108</td>
</tr>
<tr>
<td>Days patients are treated simultaneously</td>
<td>137.5</td>
<td>108</td>
</tr>
<tr>
<td>2 simultaneous</td>
<td>9.5</td>
<td>20.9</td>
</tr>
<tr>
<td>3 simultaneous</td>
<td>2.0</td>
<td>6.0</td>
</tr>
<tr>
<td>4 simultaneous</td>
<td>2.0</td>
<td>6.0</td>
</tr>
<tr>
<td>5 simultaneous</td>
<td>2.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Days patients are treated simultaneously</td>
<td>203.5</td>
<td>203.5</td>
</tr>
<tr>
<td>2 simultaneous</td>
<td>203.5</td>
<td>203.5</td>
</tr>
<tr>
<td>3 simultaneous</td>
<td>203.5</td>
<td>203.5</td>
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<tr>
<td>4 simultaneous</td>
<td>203.5</td>
<td>203.5</td>
</tr>
<tr>
<td>5 simultaneous</td>
<td>203.5</td>
<td>203.5</td>
</tr>
</tbody>
</table>

min, minimum; max, maximum; obs, observed events in 1992; NA, not available.
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Original research

Figure 2 The number of occasions two to six patients will be treated at the same time related to the number of patients requiring treatment annually in a situation with an unlimited number of ECMO facilities.

Figure 2 shows that, even if 60 patients fulfil the ECMO criteria annually, there would hardly ever be an occasion on which six patients would need treatment at the same time. However, the assumption that an unlimited number of facilities will be available does not seem realistic. If the number of treatment facilities is limited, some patients will have to be referred to facilities abroad, or be treated conservatively. Depending on the number of facilities and the number of patients requiring treatment annually, it is estimated that between zero and 30 patients will have to be referred to facilities abroad (see Figure 3). If only one facility is established while 60 patients present annually, as many as 50% of the patients presenting to that facility will have to be referred abroad. In Figure 4, the number of occasions on which patients will have to be treated simultaneously is shown for two to 60 patients requiring treatment annually and for two to five ECMO facilities.

Facing an increase to 56 patients annually (one in

Figure 3 The percentage of patients that will have to be referred to ECMO centres outside the region, if 1–5 facilities are available in the region and 6–60 patients require treatment annually.

Figure 4 The number of occasions two to five patients will be treated simultaneously, if 2–5 facilities are available, related to the number of patients annually requiring treatment. Patients that are referred to centres outside the region are included in the number of patients annually requiring treatment but excluded from the patients treated simultaneously.

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Table 3 Results of the sensitivity analysis for the increase in the duration of treatment in the 1992 situation, and several alternative scenarios

<table>
<thead>
<tr>
<th></th>
<th>1992 situation</th>
<th>Alternative scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>29 patients</td>
<td>56 patients</td>
</tr>
<tr>
<td></td>
<td>3 facilities</td>
<td>3 facilities</td>
</tr>
<tr>
<td>Increase in the duration of treatment in days</td>
<td>+1</td>
<td>+2</td>
</tr>
<tr>
<td>Patients referred for treatment elsewhere</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Occasions patients treated simultaneously (after referral)</td>
<td>9.0</td>
<td>10.4</td>
</tr>
<tr>
<td>2 simultaneous</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>3 simultaneous</td>
<td>9.0</td>
<td>10.4</td>
</tr>
<tr>
<td>4 simultaneous</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>5 simultaneous</td>
<td>9.0</td>
<td>10.4</td>
</tr>
<tr>
<td>Days at least 1 patient is treated</td>
<td>150.2</td>
<td>166.6</td>
</tr>
<tr>
<td>Days patients are treated simultaneously</td>
<td>37.0</td>
<td>48.3</td>
</tr>
<tr>
<td>2 simultaneous</td>
<td>5.9</td>
<td>8.6</td>
</tr>
<tr>
<td>3 simultaneous</td>
<td>7.7</td>
<td>8.6</td>
</tr>
<tr>
<td>4 simultaneous</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>5 simultaneous</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

+1, an increase of 1 day; +2, an increase of 2 days.

Discussion

Although the planning of all health care facilities is advisable, the planning of ECMO facilities is particularly important since the patients involved cannot be placed on a waiting list. Patients who cannot be treated because of a shortage in facilities in a region have to be treated conservatively or be referred to other regions. Planning is necessary not only when ECMO is introduced in a region but also when changes in the number of patients requiring ECMO occur. Such changes, both increases and decreases, could occur through changes in the indications for treatment after publication of the results of randomised trials, through changes in the alternative treatments and through improvements in the technique itself.14,15,16 An increase in the annual number of patients may lead to higher levels of occupancy of the facilities, causing an increase in referrals to facilities outside the region. If the number of ECMO facilities is subsequently increased, the number of patients for whom facilities have to be found outside the area decreases. But, if too many facilities are established, money will be spent on facilities that will be left unoccupied for most of the year. An ECMO facility costs about DFL 300 000 (1 DFL = 0.58 US$ = £ 0.38 = 0.47 ECU in June 1996) and initial investments for training of specialised personnel, both physicians and nurses, could amount to over DFL 50 000. If an ECMO facility is left unoccupied for a year, the fixed costs for interest, depreciation and maintenance, amounting to roughly DFL 70 000 a year, will still have to be met. If an ECMO facility is only occupied infrequently the salaries of the ECMO personnel will still have to be paid if they cannot be temporarily employed elsewhere. But such temporary employment may cause problems when an ECMO patient arrives unexpectedly for urgent treatment. Also, the existence of spare capacity could lead to a relaxation in the eligibility criteria for ECMO treatment, causing increased use by patients who do not need ECMO to survive, which in turn decreases the cost-effectiveness of the technology. Careful planning of the number of facilities may prevent these effects.

Planning problems in which random processes play a major role, such as the presentation of ECMO patients, can be partially solved by micro-simulation models. Of course, models are abstract representations of reality, and, as stated by Feest and Harrison, they are only as good as the data fed into them.20 But, although they have their limitations, they provide information that can be used in the planning of health care facilities. Most of the planning in health care with the aid of micro-simulation was done for renal services and hospital bed requirements.21–26 Unfortunately, the results were mainly published in journals specialising in operational research, not read by most health care workers.13,24,25,27

The micro-simulation model for the planning of ECMO facilities shows that in The Netherlands – if there is no change in the average duration of treatment – an
increase to 56 patients a year can take place without
an increase in ECMO facilities, if between three and four
referrals to centres elsewhere are accepted and feasible.

The acceptability or feasibility of these referrals turn out
to be crucial points in the planning, because it is not
clear who is to decide on these issues. If these referrals
are not accepted or are not feasible, an increase in facil­
ities has to be balanced against an investment in facilities
which will not be occupied frequently. The model also
shows that, even after an increase to 56 patients per
year, the marginal contribution of a fifth facility is very
small. Due to the geographical spread of facilities and
the patients, the occupancy rate may increase, but this
increase will be at the expense of the occupancy rate of
the other four facilities.

The current model only includes data on the occupa­
ancy of facilities. If reliable data on costs and their
relation to the number of patients are available (e.g.
the annual number of patients at which additional
personnel should be hired and trained, and the number
of additional nurses required if patients are treated in
two facilities instead of one), the model could be
extended to include these data. After such extension,
the model could be used to calculate the costs that
would have to be incurred to prevent one referral to a
centre abroad or outside the region, which would give
another dimension to the discussion on the acceptability
of referrals abroad. For example, if only fixed costs for
interest, depreciation and maintenance are taken into
account, setting up a fourth facility in the scenario with
56 patients annually would cost approximately DFL
70 000 annually and would prevent (3.5 - 0.8 =) 2.7 re­
ferrals abroad (Table 2) at an average cost of (70 000 /
2.7 =) DFL 26 000 per prevented referral in interest,
depreciation and maintenance of the ECMO equipment
only. Costs for additional personnel would have to be
added to this.

In countries with large differences in the geographic
distribution of patients requiring ECMO treatment
due to transport problems, geographically remote areas
or unevenness in the incidence of cases, the model
cannot be applied to estimate the number of ECMO
facilities required on a national level, but it can be used
to estimate the need for ECMO facilities in smaller sub­
regions with a homogeneous patient distribution. For
The Netherlands, the geographical distributions of facil­
ities and patients are not very important for planning
purposes, because it is a small country and newborn
babies are relatively easily transported in ambulances
and helicopters. In fact, specialised neonatal care in
The Netherlands is organised on a national rather than
on a regional basis, with a central coordinating system.

The current study shows that the acceptability and
feasibility of referrals to centres outside the region – or
abroad – is an important issue which European health
care planners will have to consider. The study also
shows that it is possible to plan the number of ECMO
facilities required in a region with relatively simple tools.
Such planning may help ECMO centres in their deci­
sions as to whether or not to invest in extra facilities in a
changing area of health care. The results of the current
study were used by policymakers in The Netherlands
to support their decision to approve the provision of
neonatal ECMO in only two ECMO centres. These
centres provide a total of three ECMO facilities. For
the time being, the government has put no official limit
on the number of facilities per centre.

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