Projecting Demand for Cardiac Pacemakers

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RONEN, B., PLISKIN, J., AND FELDMAN, S.: Projecting demand for cardiac pacemakers. *A cardiac pacemaker implantation program involves substantial resources of money, facilities, and manpower. This paper presents a model for forecasting future numbers of implants, thus enabling the more efficient use of such resources. The model embraces both new implants and replacements, both short-term and long-term planning, and can be used with relevant data from any source. (PACE, Vol. 5, July-August, 1982)*

Large cardiac centers perform hundreds of pacemaker implants every year, involving the use of substantial resources of money, facilities, and manpower. These resources can best be used efficiently by projecting future demand for pacemaker implants, both new and replacement. This paper presents a model for forecasting this and thus makes possible the short- and perhaps long-term planning of the need for pacemaker purchase, implantation, and follow-up. Sensitivity analyses can determine how the various parameters affect the cardiac pacemaker implantation system and its administrative ramifications. The parameters can be assigned values that are specific in a given environment and can be periodically updated to accommodate changing technology. A numerical example is presented for Israeli data.

The Model

Pacemaker implants are divided into two groups: the initial implantation of the pacemaker and electrode, and all subsequent or replacement implants, whether for pacemaker failure, battery exhaustion, or an electrode fault. The average life of a pacemaker is about 2 to 3 years for those with mercury batteries and between 4 and 7 years for those with the newer lithium batteries.

Patients who have had a pacemaker for less than a year are distinguished from those who have had it for more than one year.[1] Fig. 1 illustrates the possible states of a system and patient flows.

Let

- X_{1t} = Population at risk in year t.
- X_{2t} = Total number of implants in year t.
- X_{3t} = Number of patients surviving their first year with a pacemaker (at the end of year t).
- X_{4t} = Number of patients alive who have had a pacemaker for more than one year (at the end of year t).

We define the following parameters:

- μ = Proportion of people requiring a pacemaker implant (an "implant parameter").
- λ = Average lifetime of a pacemaker.
- d_1 = Proportion of patients who die in the first year after a first implant.
- d_2 = Proportion of patients dying each year of those who have had a pacemaker for more than one year.

The following relations describe the various pools and patient flows (see Fig. 1):

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Received August 5, 1980; revised February 17, 1981; accepted March 19, 1981.

$$X_{2t} = \mu X_{1t} + \frac{1}{\lambda-1} X_{4t} \tag{1}$$

$$X_{3t} = \mu (1-d_1) X_{1t} \tag{2}$$

$$X_{4,t+1} = \frac{X_{4t} + \mu(1-d_1) X_{1t}}{1+d_2} \tag{3}$$

Equation (1) states that the total number of yearly implants is the sum of the number of first implants in the population and the number of replacements during that year. Equation (2) gives the survivors of first year implants. Equation (3) gives the number of patients carrying an implant at the end of year t+1 (excluding those who died during year t+1) as a function of the number of implants at the end of the previous year (t) and the population at risk during year t.

In planning medical logistics and the number of pacemakers to order, the important figure is the number of implants per year (X_{2t}). The number of patients with implanted pacemakers alive at the end of each year (X_{3t} and X_{4t}) is required in planning follow-up.

Evaluating the Parameters

The variability of some of the parameters over different populations may be relatively small but some parameters' values may be highly specific to a given population and must be evaluated separately in each application of the model. Even within a given population, some of the parameters may vary as a function of time. However, the model is very flexible and can accommodate any parameter values as well as periodic updating of previously used values.

The data referred to in this section, as well as in the numerical example of the next section, draw mostly from experience at the Chaim Sheba Medical Center in Israel.

The Determination of μ

This is the proportion of patients receiving a (first) pacemaker implant in the population. A possible source for this proportion is to look at incidence figures of conditions requiring the use of an electronic pacemaker, mostly cases of heart blocks. However, not every discovered case of heart block requires immediate pacemaker implantation, if at all, so the yearly incidence of the condition may not be an accurate estimate of the actual proportion of patients receiving a pacemaker implant.

Data collected in Israel during 1973 to 1975 indicate a yearly implantation rate of about 100

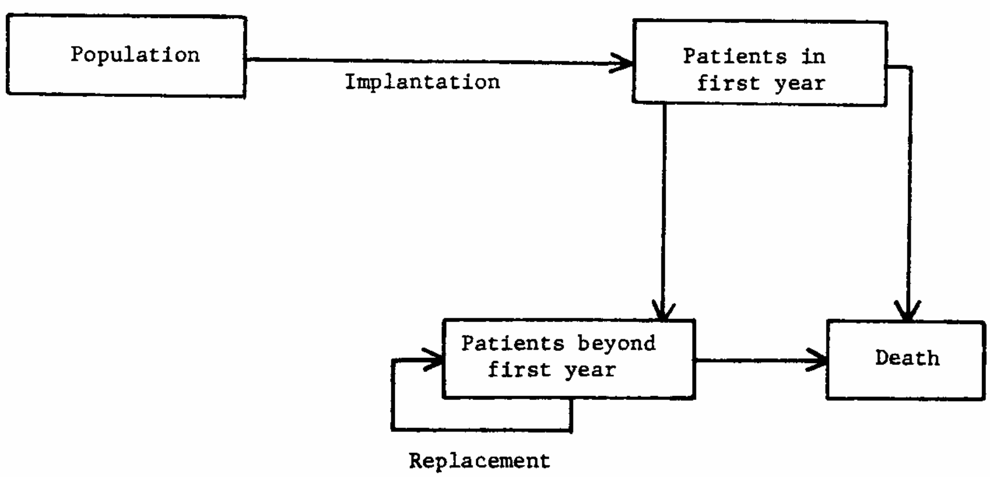

Figure 1. *States and Patient Flows*

new implants per million population[1] which implies $\mu = 10^{-4}$. In New Jersey (U.S.A.) the implantation rate was 270 per million[1] (or $\mu = 2.7 \times 10^{-4}$). This apparent difference in implantation rates may result from (1) underlying difference in the incidence of the disease in different populations having different age mixes, (2) different criteria for referring a diseased patient for pacemaker implantation, (3) differences in health insurance, or (4) different capacities to perform implantations. The last source may be due in part to differences in the number of cardiologists.

The important message here is that for every population a separate determination of μ is needed and estimating from other sources may be inappropriate.

Evaluating d_1 and d_2

The one-year mortality probabilities for patients in the first year after a first implant and for patients who have had a pacemaker for more than one year are given by d_1 and d_2, respectively. Israeli experience[1] indicates that $d_1 = 0.125$ and $d_2 = 0.06$. In Britain d_2 is less than 0.05.[2] The five-year survival in Israel is 68% while in the U.S. it is approximately 50%.[1] The data were collected separately for two types of patients, depending on the cardiac problem: patients with brady-tachyarrhythmias (about 15%), and patients with AV block (85%). However, the survival probabilities d_1 and d_2 are from both groups aggregated.

Again, different populations or settings imply different survival rates. Here too, differences in age mixes or criteria for implantation, varying skills of implantation teams and other underlying conditions can explain differences in survival. Our model can accommodate whatever data are relevant in a given setting.

Assessing λ

The average lifetime of a pacemaker type takes into account defective and non-defective units. The expected lifetime for the older mercury battery pacemakers was about 2.5 years. The newer lithium battery types have a life span of between 4 and 7 years. Whatever the setting, the appropriate λ should be used. When detailed data are not available, λ should be assumed to be the average life span of a non-defective pacemaker. If in a given implantation program there are patients with pacemakers having different life expectancies, one of two things can be done. We could use a λ which is a weighted average of the different λ's where the respective weights are the number of patients receiving each type of pacemaker; or, we could modify the state-flow model of Fig. 1 to accommodate separate states for the different pacemaker types and easily derive the relevant equations and relations.

The customary scenario for a given setting or medical center is a slow phasing out of older type pacemakers with a concurrent introduction of newer ones, thus creating a shift in the average λ. One of the convenient features of the model is the capability to update periodically the parameters as new data or technological innovations are available. If, for example, we wish to use the model for short-term planning (e.g., 1 to 3 years) the changing values of λ are not that meaningful. However, for long-term planning (5 to 10 years) we may anticipate a gradual increase in the average λ and use increasing values for λ for successive years. Since most current programs use lithium pacemakers, we are quite safe using a constant λ in planning for the coming years. If a sudden breakthrough occurs, we can always modify the projections and planning that is based upon them.

A Numerical Example: Israeli Data

For the Israeli population we will use $\mu = 10^{-4}$, $\lambda = 4$, $d_1 = 0.125$ and $d_2 = 0.06$. Equations (1)-(3) now become:

$$X_{2t} = 10^{-4}X_{1t} + 0.33X_{4t},$$

$$X_{3t} = 0.875 \times 10^{-4}X_{1t},$$

and

$$X_{4,t+1} = 0.943X_{4t} + 0.825 \times 10^{-4}X_{1t}.$$

Taking the end of 1980 as the starting point, the Israeli population was about 3,800,000 and can be assumed at that level for an additional year or two. Thus $X_{1,1980} = X_{1,1981} = 3.8 \times 10^6$. The current patient population (already with a pacemaker) is about 2000 (i.e., $X_{4,1980}$). Thus, the total number of implants (X_{2t}) in 1981 will be:

$$X_{2,1981} = 10^{-4} \times 3.8 \times 10^6 + 0.33 \times 2000 = 380 + 660 = 1040.$$

Thus, 1040 pacemakers will be needed in 1981. (The first part gives new implants and the second replacements.) The number of patients with new implants at the end of 1981 is:

$$X_{3,1981} = 0.875 \times 10^{-4} \times 3.8 \times 10^6 = 333.$$

The total number of patients having a pacemaker for more than one year at the end of 1981 will be:

$$X_{4,1981} = 0.943 \times 2000 + 0.825 \times 10^{-4} \times 3.8 \times 10^6 = 2200.$$

Discussion

There is, of course, concern about the various assumptions employed in the model and the resulting implications on the accuracy of the projections. One can argue that the model is not complex enough, thus not capturing an accurate representation of the situation. True, we could have considered fewer time intervals or the patient population could have been subdivided according to age groups and disease types exhibiting different behavior. We could have modeled population dynamics, both in terms of aging and in terms of immigration and emigration. We would perhaps obtain a somewhat more accurate representation, but at the expense of providing a degree of complexity that would make the medical profession reluctant to use it on a routine basis, not to mention the need to assess the value of many more parameters. Experience shows that the more successful models routinely employed are the simpler ones.

Projecting dialysis needs provides a good example. Many models have been developed to forecast dialysis needs, some providing great detail of patient flow for every month of a given year. Yet a rather simple model[9] that considers only yearly intervals and that does not account for different age structures of the population has been successfully used for the last eight years in the U.S. and provides formal guidelines for the Determination of Need Program at the Department of Public Health in Massachusetts.

The model presented in this paper allows for flexibility in using various data and parameters; hence it can be suited for different settings. The model has some underlying assumptions such as the actual timing of implantation in a given year. For example, we assume that all pacemakers are implanted at the beginning of the year. This is a rather common assumption in such models.

In order to formulate a model one needs to make assumptions. If decisions or projections are made without a formal analysis or model, all the assumptions are made anyhow, but they are implicit. It is better to have the assumptions explicit within a model, thus exposing them to further discussion, testing and updating, something that cannot be done if they are implicit.

It may be difficult to obtain good estimates regarding the "implant parameter," μ. One may feel more comfortable trying to assess the actual number of new implantees for each year, i.e., the first part of equation (1). This could be done by looking at past experience and observing possible trends. Pacemaker manufacturers can be approached to provide data on the number of pacemakers purchased but because of commercial reasons they will usually not release such data and especially not data relating to specific medical centers. Even if we were to obtain figures from manufacturers we could not know whether all the pacemakers in a given shipment were implanted during a given year.

The model can be adequate for short-term planning. It can also provide reasonable predictions for a more distant horizon provided the parameters and assumptions are periodically updated to account for changing trends, technological innovations, changes in age or disease structure, etc. Our estimates are deterministic. Performing sensitivity analyses by varying the parameters within reasonable limits or performing computer simulation can give some indication on the variation in the estimates, thus perhaps accounting for some underlying uncertainties that are not accommodated by the deterministic model.

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