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A MATHEMATICAL MODEL FOR SIMULATION OF CHANGES IN TUBERCULOSIS PREVALENCE DUE TO ENHANCED INTERVENTION

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Computer simulation is a tool that can be used for interpreting data on medical intervention of wide spread diseases and for comprehending its effects on their prevalence and their incidence. This paper describes briefly a mathematical model(l) that has been recently constructed for analysing the effects of rapid expansion of Directly Observed Treatment (DOT) under the Revised National Tuberculosis Control Project (RNTCP) on the prevalence and incidence of tuberculosis in India.

I. INTRODUCTION

Tuberculosis (TB) accounts for over 4 lakh deaths in India every year, more than twice due to any other disease(2). Consequently, it has been given a very high priority in the Indian public health programmes. Soon after independence, India established world class research institutes and initiated national programmes to diagnose and to treat TB cases. Yet after several decades of massive efforts, the prevalence and the annual incidence of TB disease in India are estimated to have stabilised at around 505 and 187 per lakh(3). These figures are significantly above the global average, primarily because of rather low success rate for the earlier programmes (about 10%(4) for new sputum smear positive (S+) cases). An optimised treatment strategy was devised in early nineties around research results obtained in India as well as abroad to give a success rate of about 85%. The RNTCP based on the Directly Observed Treatment Short Course Strategy (DOTS strategy) has been introduced in India in phases since late nineties. This programme has now expanded to cover 40% of the population (Fig. 1) and plans are under way to double the coverage to 80% of the population in the next two to three years.

It is only natural to ask how quickly this rapid expansion of RNTCP is going to significantly reduce the annual incidence and the prevalence of TB in India. A quantitative answer appears possible with available tools of mathematical modeling and computer simulation. Indeed such techniques have been used internationally to examine impact of various strategies for TB and other diseases(3,5). However the technique has to be adapted to meet the specific requirements of the Indian scene. For instance, one has to account for a dynamic private sector, including strong (non-profit) non-governmental organisations (NGO). As the previous programmes using earlier treatment regimens are being replaced over time, the transition has also to be dealt with. In addition, one has to reckon with a significant part of population opting for non-allopathic treatments, including ayurvedic, unani, and homeopathic modes. Finally, the internationally available models allow for age structure of the TB cases but not the gender structure. There is intense interest in gender issues in the present context. So the model has to be built in such a way that it deals with gender and age structure of the population and the TB cases. On the other hand, detailed demographic information on the age and gender structure of the population is available from the Census of India. Also, the RNTCP compiles quarterly data reports on diagnosis and treatment at district, state and country level. The model has to be designed to utilise this information. The model has no doubt to deal with the absence of comprehensive medical statistics from the private sector, which includes a large component of small-scale medical service providers of allopathic and other treatments.

A brief review of mathematical models for TB is given in the next section. It is followed by a section outlining the present model. Finally a few concluding remarks are made.

II. A BRIEF REVIEW OF MATHEMATICAL MODELS FOR TB

Mathematical models used for spread of diseases are called dynamical models as they describe change taking place over time. They are generally either deterministic or stochastic. The former type of models is more suitable for a large population and for changes over relatively long periods of time. The latter type of models is more suitable for relatively smaller populations and relatively short periods of time. The rules governing the temporal change in the latter type are in probabilities and the conclusions are also in terms of probabilities. The former has, in contrast, deterministic rules and is not cast in a statistical framework.

The focus in the first works(6-8) of the models for TB was to incorporate the known epidemiology of TB and to elucidate the role of various processes. To

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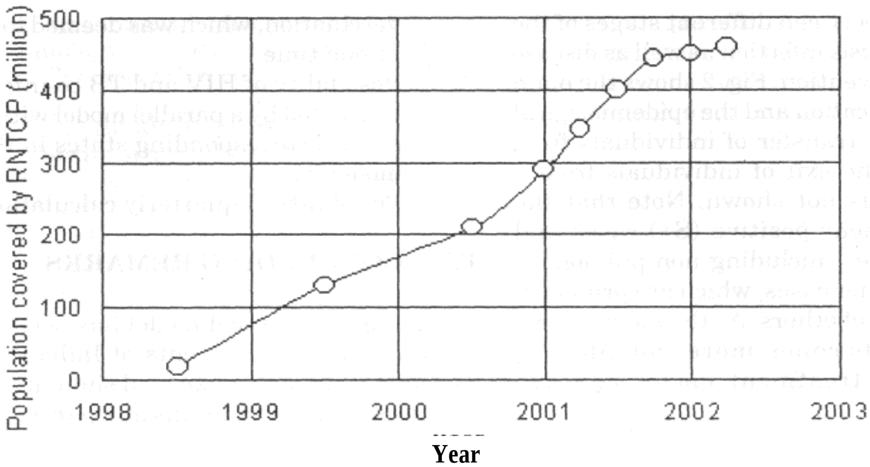
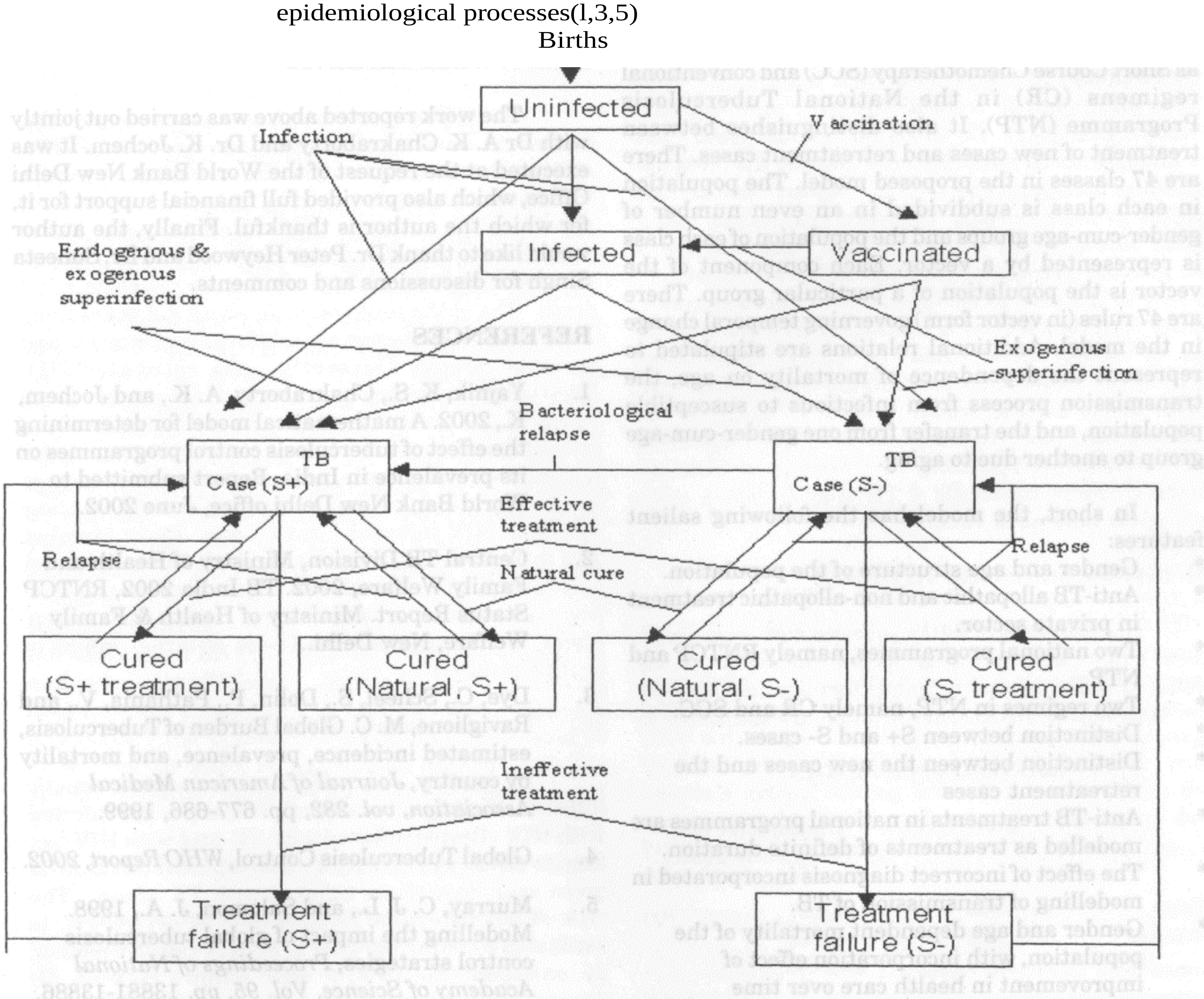
Fig. 1 Expansion of RNTCP in India



Data source: TB India 2002, RNTCP Status Report(2) & www.tbcindia.org

Fig. 2 A conceptual diagram showing the main features of the classification and the epidemiological processes(1,3,5)



put it simply, the population is divided into several classes to differentiate between different stages of the development of tuberculosis infection as well as disease and the progress of intervention. Fig. 2 shows the main features of such a classification and the epidemiological processes that result in transfer of individuals from one class to another. The exit of individuals from a class due to mortality is not shown. Note that the distinction between smear positive (S+) cases and smear negative (S-) cases, including non-pulmonary cases, is to track the former cases, which are primarily responsible for infection of others. As the models have evolved, they have become more complex to differentiate between treatment modes and age dependent processes.

III. THE PROPOSED MODEL

The proposed model uses a finer classification than indicated in Fig. 2, as it has to distinguish between various anti-TB treatments in the private sector and in various regimens in public sector, such as Short Course Chemotherapy (SCC) and conventional regimens (CR) in the National Tuberculosis Programme (NTP). It also distinguishes between treatment of new cases and retreatment cases. There are 47 classes in the proposed model. The population in each class is subdivided in an even number of gender-cum-age groups and the population of each class is represented by a vector. Each component of the vector is the population of a particular group. There are 47 rules (in vector form) governing temporal change in the model. Additional relations are stipulated to represent the dependence of mortality on age, the transmission process from infectious to susceptible population, and the transfer from one gender-cum-age group to another due to aging.

In short, the model has the following salient features:

* Gender and age structure of the population.
* Anti-TB allopathic and non-allopathic treatment in private sector.
* Two national programmes, namely RNTCP and NTP.
* Two regimes in NTP, namely CR and SCC.
* Distinction between S+ and S- cases.
* Distinction between the new cases and the retreatment cases
* Anti-TB treatments in national programmes are modelled as treatments of definite duration.
* The effect of incorrect diagnosis incorporated in modelling of transmission of TB.
* Gender and age dependent mortality of the population, with incorporation effect of improvement in health care over time
* The effect of Bacille Calmatte-Guerin (BCG) vaccination, which was deemed to be substantial at one time.
* Possibility of HIV and TB co-infection cases to be treated by a parallel model with linkages with several corresponding states in the main model(23).
* Possibility of quarterly calculations.

IV. CONCLUDING REMARKS

A mathematical model has been constructed to meet specific requirements of Indian medical scene. The next stage is to make trial simulation with various options of initial conditions and parameter estimation techniques. Once a measure of confidence is established, the model can be used for retrospective analysis and for future projections. Once a measure of experience becomes available with comparison with available data, further refinements can be introduced.

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REFERENCES

1. Yajnik, K. S., Chakraborty, A. K, and Jochem, K., 2002. A mathematical model for determining the effect of tuberculosis control programmes on its prevalence in India. Report submitted to World Bank New Delhi office, June 2002.

2. Central TB Division, Ministry of Health and Family Welfare, 2002. TB India 2002, RNTCP Status Report. Ministry of Health & Family Welfare, New Delhi..

3. Dye, C., Scheel, S., Dolin, P., Pathania, V., and Raviglione, M. C. Global Burden of Tuberculosis, estimated incidence, prevalence, and mortality by country, *Journal of American Medical Association, vol. 282,* pp. 677-686, 1999.

4. Global Tuberculosis Control, *WHO Report, 2002.*

5. Murray, C. J. L., and Salomon, J. A., 1998. Modelling the impact of global tuberculosis control strategies, *Proceedings of National Academy of Science, Vol. 95, pp.* 13881-13886.

6. Waaler, H., Geser, A., and Andersen, S., 1962. The use of mathematical models in the study of the epidemiology of tuberculosis, *American Journal of Public Health, vol. 52, pp.* 1002-1013.

7. Blower, S. M., Small, P. M., and Hopewell, P. C., 1996. Control strategies for tuberculosis: new models for old problems, *Science, vol. 273,* pp. 497-500.

8. Blower, S. M., McLean, A. R., Porco, T. *C.,* Small, T. C., Hopewell, P. C., Sanchez, M. A., M. A., and Moss, A. R., 1995. The intrinsic transmission dynamics of tuberculosis *epidemics, Natural Medicine, vol. 1,* pp. 815-821.