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Computer Simulation Modelling for the Prevention of Diabetes Mellitus (Prameha)

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Abstract: In India the care of people with type 2 diabetes mellitus could be with western system of medicine or an Indian system of medicine called Ayurveda. This study is concerned with the modelling for the care of people with type 2 diabetes mellitus through Ayurveda. In Ayurveda diabetes mellitus is termed as 'prameha' which is has become a serious health problem in many countries. We describe the use of an individual level systems modelling approach for the progression of prameha that has been used for cost-effectiveness evaluations of various prevention and patient care options. The adopted framework incorporates prameha risk groupings, formulated using the expert opinion which are then fed into a developed simulation model, at the level of individual patients. A multidisciplinary task group, comprising of clinicians and health care modellers, guided the necessary modular development involving the definition of risk groups in the community, natural history of prameha and options for early detection and treatment.

Key words: Diabetes mellitus, prameha, ayurveda, simulation modelling

INTRODUCTION

Diabetes mellitus is a chronic progressive disorder that affects millions of people worldwide with devastating human, social and economic impact (Watkins, 1993). Today, around 250 million people worldwide are living with Diabetes and by 2025 this total is expected to increase to over 380 million (Hossain *et al*., 2007). The prevalence of diabetes has reached epidemic proportions. India has today become the diabetic capital of the world with over 20 million diabetics and this number is projected to increase to 57 million by 2025 (King *et al*., 1998; Sridhar, 2000). WHO predicts that developing countries will bear the brunt of this epidemic in the 21st century. Currently, more than 70% of people with diabetes live in low and middle income countries. An estimated 285 million people, corresponding to 6.4% of the world's adult population, live with diabetes in 2010. The number is expected to grow to 438 million by 2030, corresponding to 7.8% of the adult population. While the global prevalence of diabetes is 6.4%, the prevalence varies from 10.2% in the Western Pacific to 3.8% in the African region. However, the African region is expected to experience the relatively higher increase. Over 70% of the current cases of diabetes occur in low and middle income countries. With an estimated 50.8 million people living with diabetes, India has the world's largest diabetes population, followed by China with 43.2 million. The largest age group currently affected by diabetes is between 40-59 years. By 2030 this 'record' is expected to move to the 60-79 age group with some 196 million cases (IDF, 2011). Diabetes mellitus is one of the major causes of premature illness and death worldwide. Non-communicable diseases including diabetes account for 60% of all deaths worldwide.

Lack of sufficient diagnosis and treatment: In developing countries, less than half of people with diabetes mellitus are diagnosed. Without timely diagnoses and adequate treatment, complications and morbidity from diabetes rise exponentially. Type 2 diabetes mellitus can remain undetected for many years and the diagnosis is often made from associated complications or incidentally through an abnormal blood or urine glucose test (Hossain *et al*., 2007; Behnam-Rassouli *et al*., 2010).

Diabetes costs-a burden for families and society: The financial burden borne by people with diabetes and their families as a result of their disease depends on their economic status and the social insurance policies of their countries. In the poorest countries, people with diabetes

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and their families bear almost the whole cost of the medical care they can afford. The World Health Organization (WHO) predicted net losses in national income from diabetes and cardiovascular disease of International Dollars (ID) 557.7 billion in China, ID 303.2 billion in the Russian Federation, ID 336.6 billion in India, ID 49.2 billion in Brazil and ID 2.5 billion in Tanzania (2005 ID), between 2005 and 2015 (WHO, 2005).

History of diabetes mellitus: The ancient Indian scriptures Rig and Atharva Vedas (around 5000BC) mention health and diseases including 20 types of obstinate urinary disorders called Prameha. Prameha can be translated as, 'passing of excessive urine'. Over time an Indian system of medicine, called Ayurveda, has evolved and two important sources for this impressive knowledge and practice are the writings of physicians Charaka (Sharma, 1981) and Sushruta (Bhishagratna, 1991). It is believed that Charaka and Sushruta practiced Ayurveda around 200BC. Ayurveda is a comprehensive, theoretical, diagnostic and clinical system (Bodeker, 2001) with an emphasis on prevention. Figure 1 shows a classification of Prameha by people and by disease and we see that 4 types of Prameha are incurable and the other 16 can either be cured or the condition of the person can be stabilised on treatment. The diagnosis of a particular type of disease is sometimes made from detailed examinations of urine.

The correspondence between diabetes mellitus and Prameha has been discussed by Murthy and Singh (1989), Roy *et al.* (1992) and Manyam (2004). The most serious form of Prameha is Madhumeha where the disease is well advanced possibly through an improper early management of less serious types of Prameha. Madhumeha corresponds to diabetes mellitus. The symptoms described by Sushruta for a person born with Madhumeha are similar to the symptoms of type 1 diabetes mellitus. Ayurvedic descriptions for a person who acquires Madhumeha correspond to the descriptions for a person with type 2 diabetes mellitus and these include family history of diabetes, obesity, improper diet, lack of exercise etc. (Sharma, 1981).

The word diabetes mellitus was used in 2nd century AD to describe passing of excess urine. Discovery that damaged pancreas and in particular damage to a cluster of cells called Islets of Langerhans causes diabetes was made in the 19th century. Insulin was discovered in 1922 and subsequently injection of manufactured insulin was a very major advancement in controlling diabetes in the western allopathic system of medicine. At present, diabetes if detected early can be treated quite successfully (Haque *et al.*, 2011).

Prameha purvaroopa (pre-diabetes) signs and symptoms: Often, pre-diabetes has no signs or symptoms. It is a condition, if left unattended; the person might go on to develop diabetes. Allopathic system of medicine treats it as a condition and medicines are prescribed to 'treat' prediabetes. But since it is only a hint that the person 'might' develop diabetes in future, it can be very well reversed with suitable lifestyle changes and by including some very simple herbs in diet. Ayurveda explains the following pre diabetes symptoms: Coating (on teeth) and secretion (from eyes/nose), depleting oral hygiene, burning sensation in feet and palms, a feeling of stickiness in whole body, lethargy of mind and body

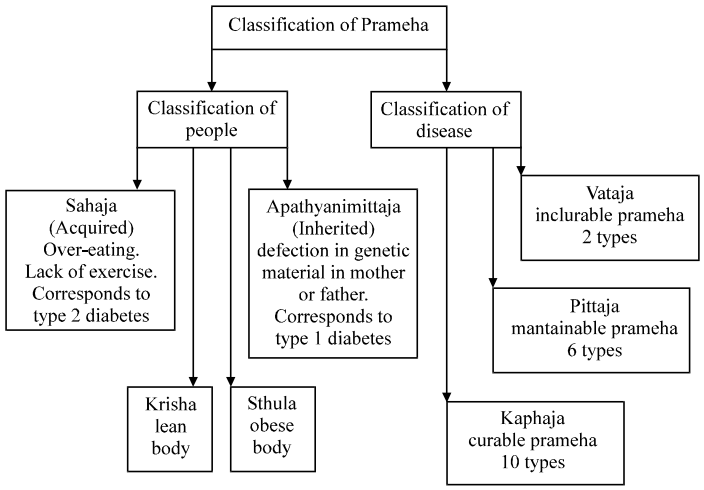

Fig. 1: Classification of prameha by people and disease

etc. According to modern parameters, a fasting blood sugar level of 100-125 mg dL^{-1} and post prandial blood sugar level of around 140 mg dL^{-1} is considered as pre diabetes (Bhishagratna, 1991).

Ayurveda for prevention of prameha and madhumeha (Type 2 diabetes mellitus): Ayurveda is a traditional Indian system of medicine that evolved in India over a very long period of time with roots in the ancient sacred Vedas of the Indus river civilization (Svoboda, 1992). Progress in Ayurveda, greatly hindered by the British rule in India, has been very marked since India became independent in 1947. At present, Ayurveda is a part of the national health system in India and the interest in Ayurveda is rapidly spreading to a number of countries across the globe. The following eight subspecialties of Ayurveda indicate the wide scope of Ayurvedic medicine.

- Kayachikitsa-internal medicine
- Shalya tantra-general surgery
- Shalakya-ophthalmology
- Kaumar Bharitya-paediatrics and obstetrics/ gynaecology
- Bhutavidya-psychiatry
- Agada tantra-toxicology
- Rasayana tantra-nutrition, detoxification and rejuvenation
- Vajikarana-sexual health and aphrodisiacs

In Ayurveda, the emphasis is given on establishing and maintaining the balance of the various systems within the human body, rather than focusing on the treatment of individual symptoms. A fundamental concept is that a human being has an inherited constitution which can be described by various combinations of three fundamental "energies" called doshas. The three doshas are Vata, Pitta and Kapha. A person with a good inherited constitution can become ill due to imbalances in the doshas and a basic aim of Ayurvedic treatments would be to remove the imbalances in doshas. This concept of disturbed balance of doshas could mean that with Ayurveda two persons with the same outwardly visible symptoms may require very different treatments. In general, Ayurvedic treatments include a typical combination of: diet, exercise, massage, herbal remedies, yoga and meditation (Manyam, 2004; Hankey, 2005).

Ayurveda treatment for prameha: An excellent review provides wide range of information about treatment of Ayurveda for the care of people with diabetes (Hardy *et al*., 2001). The first step in the treatment however is to determine the essential prakruti (constitution) of the individual which depends on which dosha is predominant and will reflect the energies and tendencies within. Knowledge of prakruti allows the selection of appropriate habits and lifestyle to enhance the maintenance of health and will suggest:

- The most effective means to prevent disease from arising
- The prognosis of both simple and complex diseases
- The most effective treatment
- The recuperative capacity of an individual
- The best dietary regimen for that individual
- How to compound herbal formulations to the best advantage
- The most beneficial rejuvenative program

In Ayurveda, treatment structure can broadly be classified as follows:

Shodhana-purification treatment: This aims at removal of the causative factors of somatic and psychosomatic diseases. The process involves internal and external purification through the use of Panchakarma.

Shamana-palliative treatment: Shamana involves the suppression of vitiated doshas by which the disturbed dosha returns to normal without creating an imbalance of other doshas. This is achieved by the use of appetisers, digestives, exercise, exposure to sun, fresh air etc. In this form of treatment, palliatives and sedatives are used.

Pathya vyavastha-diet and activity appropriate to ones path (pathya): Recommendations are made with respect to diet, activity, habits and emotional status with a view to impeding pathogenetic processes. The emphasis is on finding a diet that stimulates agni and optimises the digestion and assimilation of food in order to ensure strength of the dhatus (tissues).

Nidana parivarjan-avoidance of disease causing factors: Known disease causing factors in the diet and lifestyle of the patient are avoided in order to determine the aggravation of the associated doshas.

Sattvavajaya- psychotherapy: This mainly concerns the area of mental disorders and includes a wide range of approaches to restrain the mind from desires for unwholesome objects and cultivate courage, memory and concentration.

Rasayana-rejuvenation therapy: Healthy rasa dhatu is essential to produce healthy blood and other tissues.

Rasayana is the process of replenishment of the quality and quantity of the body's fluid. Rejuvenative substances enhance ojas, prevent the premature damage to body tissues and promote an individual's health through strength and vitality.

Also the other treatment options used in Ayurveda are: Dhyana-meditation, Ahar-diet, Abhyanga-self massage, Aushadhi chikitsa-herbal therapies, Dincharya-daily routine, Ritucharya-seasonal routine, Anashana-fasting, panchakarma The five purification therapies, Yoga-Stretching exercise. In addition, there are several types of glucose-lowering plant drugs in Ayurveda which have been tested for their efficacy in the treatment of prameha (Joseph and Jini, 2011; Aljamal, 2011).

It is absolutely clear that Ayurveda cannot replace allopathic medicine for the care of people with diabetes mellitus. Examples of the strengths of allopathic medicine are: insulin injections for type 1 diabetes mellitus; dialysis; and kidney transplants. However, Ayurveda has very important contribution in the prevention of type 2 diabetes mellitus (Sharma and Patki, 2010). As Fig. 1 shows according to Ayurveda there are 20 forms of prameha (urinary disorders). Four are due to Vata, 6 result from Pitta and 10 are caused by Kapha. Prameha is mainly caused by Kapha. All forms of prameha if not treated, eventually develop into Madhumeha (diabetes mellitus). This detailed classification creates a good scope for the prevention of diabetes by interventions before Prameha and before Madhumeha. In Ayurveda a collection of pre-disease signs and symptoms is called Prameha Purvaroopa and for Prameha there are many such signs and symptoms. Ayurvedic interventions for prevention of Prameha and Madhumeha could involve herbal medicines, massages, nutritional advice, yoga etc. and they would take the person's constitution, family history and prameha type into account.

NATURAL HISTORY OF PRAMEHA

The natural history model of Prameha has been formulated using expert opinion of practicing Ayurveda physician. Two differing states of Madhumeha were explained by the Ayurveda physician: 1) a mild form that consists of sweetness of body, urine and sweat in addition to the symptoms of any of the other 19 types of kaphaja, pittaja or vataja pramehas and 2) severe madhumeha, the 20th type of prameha described under vataja prameha which is incurable and can lead to death; this can be compared to diabetes mellitus (Manyam, 2004). Further discussions led to the development of the natural history given in Fig. 2 which illustrates a model for the progression of patients with Prameha.

Risk groups for prameha: The Ayurveda physician suggested that the most significant risk factor for acquiring Prameha is the person's levels of obesity and other important risk factors are diet and life style. In the western system, obesity is an overall body condition measured typically by the body mass index. In Ayurveda, in addition to an overall appearance (overall obesity) fat deposits over various parts of the body are also important and these distributed deposits can be described as partial obesity. Thus in Ayurveda obesity is summarised as the overall/partial condition. These risk factors determine the type of Prameha that a person could be at risk of developing. For example, an excessively thin person has the risk of contracting Vataja Prameha regardless of diet and life style. Excessively fat/fat people have the risk of developing Kaphaja Prameha, Pittaja Prameha and Madhumeha Tridoshaja depending on diet and lifestyle. The Ayurveda physician suggested the use of eight risk groups defined by overall/partial obesity, diet and life style. Quantifying the risk of developing the prameha in each risk group imposed a formidable challenge as no

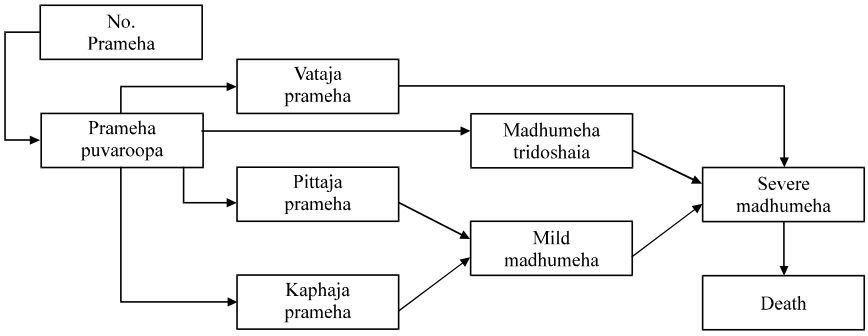

Fig. 2: Natural history of prameha

numerical data was available. A person's risk group can be easily identified by an Ayurveda physician (Elder, 2004). Table 1 shows the eight risk groups and the rough estimates of corresponding risk of developing Prameha after using the appropriate weightings (weight 1 for lower risk and weight 8 for higher risk etc.). It is interesting to note that excessively thin people have the highest risk of developing Prameha.

Transition probabilities and distributions of transition times of stay: The required transition probabilities and the durations were obtained through expert opinion (Practicing Ayurveda Physician). The Ayurveda expert was able to provide the estimates for the severest (shortest dwelling time) and the mildest (longest dwelling time) cases for each state. Weibull distribution was chosen as being the most appropriate statistical model to model the necessary transition times in each state. We estimated the parameters of Weibull distribution using percentile points (Marks, 2005). The estimations of minimum and maximum dwelling times have been used as the 5 and 95th percentile points in the algorithm to find the parameters of the Weibull distribution. Table 2 shows the estimated parameters of the Weibull distributions for the natural history transitions without any preventive treatments. The two parameter Weibull model is given by the following mathematical equation:

$$f(x) = \alpha\beta x^{\beta-1} \exp\{-\alpha x^{\beta}\} \text{ for } x \geq 0, \alpha>0 \text{ and } \beta>0$$

Table 1: Prameha risk groups

Risk group No.	Description obesity-diet/lifestyle	(%) risk of developing prameha
1	Excessively thin-any diet/life style	22
2	Medium/thin-Vata diet/lifestyle	3
3	Excessively fat/fat-Tridosha diet/lifestyle	17
4	Excessively fat/fat-Pitta diet/lifestyle	14
5	Excessively fat/fat-Kapha diet/lifestyle	19
6	Medium/thin-Tridosha diet/lifestyle	11
7	Medium/thin-Pitta diet/lifestyle	8
8	Medium/thin-Kapha diet/lifestyle	6

Interventions for prevention of prameha and madhumeha: The Ayurveda physician explained the various interventions for preventing Prameha at the Prameha Purvaroopa stage and the interventions for preventing Madhumeha at the Prameha stage. Five intervention programmes chosen for evaluation by the Prameha model are listed below.

- No intervention
- Treatment at no prameha stage for all (100% coverage)
- Treatment at prameha purvaroopa stage for all (100% coverage)
- Treatment at no prameha stage and Prameha purvaroopa stage for all (100% coverage)
- Treatment at no prameha and prameha purvaroopa stages for high risk groups 1, 3 and 5

These interventions would mean longer stays in the durations of stay in the better stages with corresponding changes in the parameters of the Weibull distributions. The approximate durations of these longer stays along with the estimate of cost of interventions were provided by expert opinion (Ajgaonkar, 1984; Upadhayay and Pandey, 1984).

A cost-effectiveness computer simulation model for prameha: The computer simulation models have been used in health research and policy since the 1960s

Table 2: Weibull parameters for transition time in years.

	Time values in years			Weibull parameters	
From → To	5th percentile	95th percentile	Mean	α (Scale)	β (Shape)
No prameha → Prameha purvaroopa-risk group 1	2.00	4.5	3.32	5.0	3.6
No prameha → Prameha purvaroopa-risk group 2	4.50	7.0	5.89	9.2	6.2
No prameha → prameha purvaroopa-risk groups 3/6	3.00	9.0	6.04	3.7	6.7
No prameha → prameha purvaroopa-risk groups 4/7	4.00	12.0	8.05	3.7	8.9
No prameha → prameha purvaroopa-risk groups 5/8	5.00	15.0	10.07	3.7	11.2
Prameha purvaroopa → Vataja prameha	2.00	7.0	4.48	3.3	5.0
Prameha Purvaroopa → Madhumeha tridoshaja	3.00	12.0	7.37	2.9	8.3
Prameha purvaroopa → pittaja prameha	5.00	15.0	10.07	3.7	11.2
Prameha purvaroopa → Kaphaja prameha	100.00	30.0	20.13	3.7	22.3
Vataja prameha → Severe madhumeha	1.00	3.5	2.24	3.2	2.5
Madhumeha tridoshaja → Severe madhumeha	1.50	6.0	3.68	2.9	4.1
Pittaja prameha → Mild madhumeha	2.50	7.5	5.03	3.7	5.6
Kaphaja prameha → Mild madhumeha	5.00	15.0	10.07	3.7	11.2
Mild medhumeha → Severe madhumeha-risk groups 4/7	1.25	3.5	2.40	4.0	2.7
Mild medhumeha → Severe madhumeha-risk groups 5/8	2.50	7.5	5.03	3.7	5.6
Severe madhumeha → Death	0.00	2.0	0.99	1.9	1.1

(Elveback and Varma, 1965; Handyside and Morris, 1967). In a review of simulation modeling in population health and health care delivery prior to 2000, Fone *et al.* (2003) identified near about 182 papers covering a wide range of topics, including hospital scheduling, communicable diseases, screening, cost of illness and economic evaluation (Fone *et al.*, 2003).The approach of using computer simulation modeling to evaluate the beneficial effects of Ayurveda is a novel one. To our knowledge, as yet no work has been published in modelling disease processes as described in Ayurveda. An operational model for prameha has been developed. This detailed simulation tool, at the level of individual patients, has been designed for use by clinicians for cost-effectiveness evaluations of various intervention and patient care options. Further, it has been shown that the operational models can be powerful tools for making effective decisions about effective and efficient health care (Shahani, 1996; Sayyad *et al.*, 2002; Sayyad *et al.*, 2011).The approach taken ensures that the model incorporates the evolved risk groups in the community, together with the natural history of the underlying disease and options for early detection and treatment of patients (Shahani *et al.*, 1994, 2008). The model was built using SIMUL8 (Simul8 Corporation, Boston, USA), a simulation software and enhanced with MS-Excel front and back-end interface (Harper *et al.*, 2003). SIMUL8 is a computer package for discrete event simulation. It allows the user to create a visual model of the system under investigation by drawing objects directly on the screen. Typical objects may be queues or service points. The characteristics of the objects can be defined in terms of, for example, capacity or speed. Once the system has been modelled a simulation can be undertaken. The flow of work items around the system is shown by animation on the screen so that the appropriateness of the model can be assessed. When the structure of the model has been confirmed, then a number of trials can be run and the performance of the system may be described statistically. Statistics of interest may be average waiting times, utilisation of work centers or resources, etc. (Shalliker and Ricketts, 2002). Figure 3 shows a screenshot of the prameha model built in SIMUL8.

Illustrative results from the model: The simulation model of the natural history incorporates eight prameha risk groups (Table 1), transition times and transition probabilities among the different states of Fig. 2, intervention options and the costs of the interventions. Information on transition time and the probability of transition and the cost of treatment for the different risk groups has been obtained using the expert opinion. The model takes a cohort of people aged more than 30 years through time. Both the cohort size and time horizon are user-defined. The transition from No Prameha to Prameha Purvaroopa is governed by each risk group's associated probability of developing Prameha (Table 1). Once a patient has made this initial transition, the patient enters the natural history model and is simulated to progress through the states (death is the final state they can reach). Dwelling times in each state are sampled from the appropriate statistical distributions, as fitted to the information obtained through the expert clinical opinion, as shown in Table 2. For example, the time from No Prameha to Prameha Purvaroopa (in years) follows a Weibull distribution with parameters $\alpha = 5.0$ and $\beta = 3.6$ for risk group 1. Movement among states is governed by user-defined probabilities.

The model allows for the evaluation of clinical interventions (Ayurveda treatments) to patients within Prameha Purvaroopa and/or Prameha states (Harper *et al.*, 2003). The effects of these interventions are modelled through changes to the transition probabilities and dwelling times in each stage. For example, patients with Prameha Purvaroopa receiving treatment might subsequently stay within the same state for the remainder of their life, thus avoiding the transition to Prameha. Associated costs of interventions are defined as the costs per patient per year (in Rupees) and the model calculates the corresponding health care costs for each intervention programme (Shahani, 1996).

Figure 4 shows the MS-Excel front-end screen used to define the risk groups for Prameha and any associated interventions. The user is allowed to change any of the following parameters: percentage of patients in each risk group, percentage from each group likely to develop Prameha, percentage of patients from each group receiving treatment in Prameha prurvaroopa and Prameha states and associated costs per patient for treatment (in Indian Rupees (Rs)). The flexibility of the developed tool allows clinicians to evaluate different treatment options targeted at different risk groups.

The cost of treatment estimates: The Ayureda Physician provided the information on the frequency of treatment at no prameha. Vamana and /or virechana therapy may be done once a year in healthy people which costs roughly Rs 2250 each. In healthy people, a non-medicated oil basti may also be used. In general one session incorporates 7 sittings costing Rs 700 at the rate of Rs 100 each. A person may have a maximum of 14 sittings each year. For treating people at prameha purvaroopa intervention adapted may be 'basti' that uses medicated oil which costs Rs 150 per

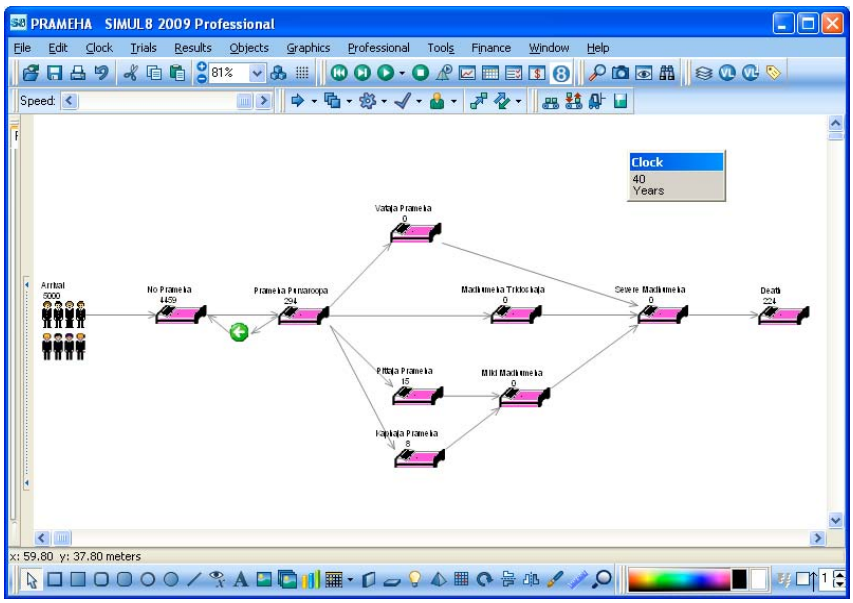

Fig. 3: A screenshot of the prameha model

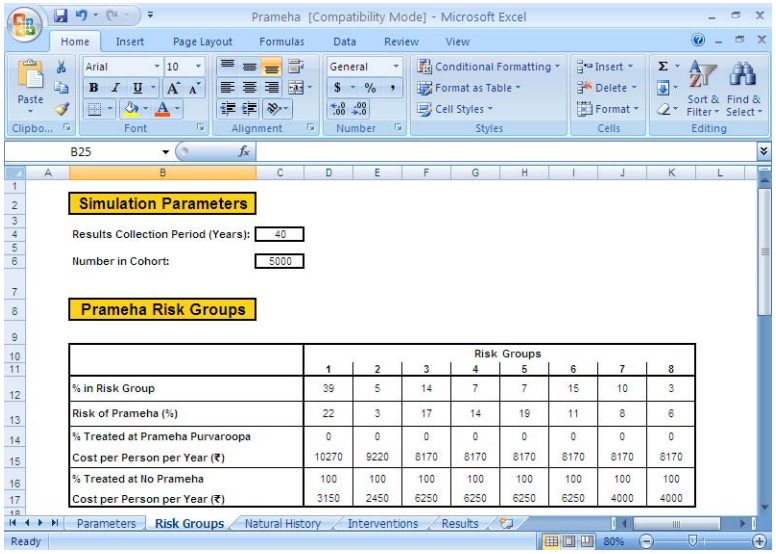

Fig. 4: Defining intervention strategies: the model front-end

sitting. In addition there are consultation and medication charges that varies considerably across different parts of India. Also Ayurveda physician may advise the investigations of modern clinical risk factors (such as fasting glucose, lipid profile etc.), the cost of such investigations has also been included in the model (Manyam, 2004).

Intervention case studies: Results from the Prameha model were obtained through simulations. A cohort of 5000 men and a cohort of 5000 women were used for the model that runs over a period of 40 years. The following response variables were recorded for each scenario: the total costs of the intervention program and the number of patients who reach at the different states of the

Table 3: Evaluation of ayurvedic preventive treatments for men No. and % of men in various stages of the model after 40 simulated years

	Intervention programmes				
Outcome	1	2	3	4	5
Develop prameha (n (% of cohort))	810(16.2)	448(8.9)	788(15.7)	447(8.9)	557(11.1)
Reach vataja Prameha (n (% of cohort)	224(4.5)	158(3.1)	212(4.2)	160(3.2)	155(3.1)
Reach madhumeha Tridoshaja (n (% of cohort))	103(2.1)	53(1.1)	65(1.3)	32(0.6)	63(1.3)
Reach pittaja Prameha (n (% of cohort))	44(0.9)	13(0.3)	14(0.3)	4(0.1)	42(0.8)
Reach kaphaja Prameha (n (% of cohort))	33(0.7)	5(0.1)	4(0.1)	0(0)	6(0.1)
Reach severe Madhumeha (n (% of cohort))	364(7.2)	220(4.4)	287(5.7)	195(3.9)	250(5.0)
Total cost of intervention (million Rs)	0	848	144	866	536

Table 4: Evaluation of ayurvedic preventive treatments for women No. and % of men in various stages of the model after 40 simulated years

	Intervention programmes				
Outcome	1	2	3	4	5
Develop prameha (n (% of cohort))	772(15.4)	420(8.4)	764(15.3)	420(8.4)	525(10.5)
Reach vataja Prameha (n (% of cohort))	202(4.0)	145(2.9)	200(4.0)	139(2.8)	135(2.7)
Reach madhumeha Tri. (n (% of cohort))	100(2.0)	55(1.1)	62(1.2)	34(0.7)	66(1.3)
Reach pittaja Prameha (n (% of cohort))	47(0.9)	12(0.2)	16(0.3)	5(0.1)	45(0.9)
Reach kaphaja Prameha (n (% of cohort))	31(0.6)	3(0.1)	5(0.1)	0(0)	4(0.1)
Severe madhumeha (n (% of cohort))	342(6.8)	209(4.2)	274(5.5)	177(3.5)	235(4.7)
Total cost of intervention (million Rs)	0	856	138	941	470

prameha over the 40 years (Harper *et al*., 2003). Table 3 and 4 show the predicted evaluations of the selected intervention options for men and women, respectively.

We see that as expected, interventions reduce the number and the percentages of people reaching the more serious stages of Prahema. For example with treatment 4 (treating all men at no Prameha stage and Prameha Purvaroopa) the percentage of men reaching Kaphaja Prameha would reduce from 0.7% (the case of no treatment) to 0% and the cost would be Rs 866 million over 40 years. The corresponding reduction for treating high risk men only would be from 0.7 to 0.1% at a cost of Rs 536 million. For severe Madhumeha the reductions would be from 7.2 to 3.9% for 100% coverage and from 7.2 to 5.0% for treating high risk men only. It is interesting to note that if all men at Prameha Purvaroopa stage are treated then only 5.7% of the population of men would develop severe madhumeha and the cost of this intervention over 40 years would be Rs 144 million only.

Similarly if all women at prameha purvarroopa stage are treated then only 5.5% of them would develop severe madhumeha and the cost of this intervention over 40 years would be Rs 138 million only which is much lesser than the cost (Rs 941 million) of treatment option 4 (treating all women at no Prameha stage and Prameha Purvaroopa stage).

Model validation: The model validation is an essential part of the model development process if models are to be accepted and used to support decision making. The methodology of model validation has been discussed by Fone *et al.* (2003) Philips *et al.* (2004) and Shah *et al.* (2010). Sargent (2005) described the general approach to 'verification and validation' of computer simulation models and specific techniques that can be used for these purposes (Sargent, 2005). The term model validation can be simplified by recognizing that the evidence supporting a given use of a model can be obtained by examining: 1) the process of model development; 2) the performance of the model and 3) the quality of decisions based on the model (Kopec *et al*., 2010). The verification of the model has been achieved on careful experimentation of the simulation, by tracing particular entities through the model and noting the performance measures to see if the changes visible in the simulation are reasonable in light of the changes made to the user's input. Expert opinion of Ayurveda physician has guided significantly the entire validation process of model development and the decision making based on the model (Venkata Raju, 2007).

CONCLUSIONS

This study has demonstrated the value of a multidisciplinary study of the care of people with prameha. The systems modelling approach adopts appropriate clinical knowledge, mathematical modelling, together with the development of easy to use models on personal computers.

India currently witnesses the escalating epidemic of diabetes and related disorders than any one country and so there is an urgent need to prevent it. It is important to understand that in the absence of any real data, expert opinion and a dynamic approach has been used in almost the entirety of the model. Much effort has been made in incorporating reality into the model by gaining as much

realistic numerical data as possible through lengthy discussions with the Ayurveda consultant.

Quantitative measures of the risk of suffering from Prameha have been formulated using the expert opinion which can be of help in the care of people with Prameha. These Prameha risk groups are then fed into a developed simulation model, at the level of individual patients, for cost-effectiveness evaluations of various intervention and patient care options. The approach taken ensures that the model incorporates the evolved risk groups in the community, together with the natural history of Prameha and options for early detection and treatment of patients. Case studies demonstrate how the model may be used to evaluate different interventions and patient care options.

Thus, in this study we demonstrate the clinically and economically beneficial effects of the Ayurveda treatment at the Prameha Purvaroopa (pre-diabetes) stage which would facilitate the prevention of diabetes in a developing country such as India. It is therefore important to create an awareness among Indians regarding the signs, symptoms and treatment of pre-diabetes.

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REFERENCES

Ajgaonkar, S.S., 1984. Ancient Indian Medicine and Diabetes. In: Diabetes Mellitus in Developing Countries, Bajaj, J.S. (Ed.). All India Medical Sciences, Mehta Offset Works, New Delhi, pp: 3-10.

Aljamal, A., 2011. Effects of bay leaves on the patients with diabetes mellitus. Res. J. Med. Plant, 5: 471-476.

Behnam-Rassouli, M., M.B. Ghayour and N. Ghayour, 2010. Microvascular complications of diabetes. J. Biol. Sci., 10: 411-423.

Bhishagratna, K.L., 1991. Sushruta Samhita. Vol. 3, Chaukhamba Orientalia, Varanasi, India.

Bodeker, G., 2001. Evaluating ayurveda. J. Altern. Complement Med., 7: 389-392.

Elder, C., 2004. Ayurveda for diabetes mellitus: A review of the biomedical literature. Altern Ther. Health Med., 10: 44-50.

Elveback, L. and A. Varma, 1965. Simulation of mathematical models for public health problems. Public Health Rep., 80: 1067-1076.

Fone, D., S. Hollinghurst, M. Temple, A. Round and N. Lester *et al*., 2003. Systematic review of the use and value of computer simulation modelling in population health and health care delivery. J. Public Health, 25: 325-335.

Handyside, A.J. and D. Morris, 1967. Simulation of emergency bed occupancy. Health Serv. Res., 2: 287-297.

Hankey, A., 2005. The scientific value of ayurveda. J. Altern. Complementary Med., 11: 221-225.

Haque, N., U. Salma, T.R. Nurunnabi, M.J. Uddin, M.F.K. Jahangir, S.M.Z. Islam and M. Kamruzzaman, 2011. Management of type 2 diabetes mellitus by lifestyle, diet and medicinal plants. Pak. J. Biol. Sci., 14: 13-24.

Hardy, M.L., I. Coulter, S. Venturupalli, E.A. Roth, J. Favreau, S.C. Morton and P. Shekelle, 2001. Ayurvedic interventions for diabetes mellitus: A systematic review. Evidence Report/Technology Assessment No. 41 (Prepared by Southern California Evidence-based Practice Center/RAND under Contract No. 290-97-0001). AHRQ Publication No. 01-E040.

Harper, P.R., M.G. Sayyad, V. de Senna, A.K. Shahani, C.S. Yajnik and K.M. Shelgikar, 2003. A systems modelling approach for the prevention and treatment of diabetic retinopathy. Eur. J. Operat. Res., 150: 81-91.

Hossain, P., B. Kawar and M. El Nahas, 2007. Obesity and diabetes in the developing world-A growing challenge. New Engl. J. Med., 356: 213-215.

IDF, 2011. Diabetes Atlas. 4th Edn., International Diabetes Federation, Brussels.

Joseph, B. and D. Jini, 2011. Insight into the hypoglycaemic effect of traditional indian herbs used in the treatment of diabetes. Res. J. Med. Plant, 5: 352-376.

King, H., R.E. Aubert and W.H. Herman, 1998. Global burden of diabetes, 1995-2025: Prevalence, numerical estimates and projections. Diabetes Care, 22: 1414-1431.

Kopec, J.A., P. Fines, D.G. Manuel, D.L. Buckeridge and W.M. Flanagan *et al*., 2010. Validation of population-based disease simulation models: A review of concepts and methods. BMC Public Health, 10: 710-710.

Manyam, B.V., 2004. Diabetes mellitus, ayurveda and yoga. J. Altern. Complement. Med., 10: 223-225.

Marks, N.B., 2005. Estimation of Weibull parameters from common percentiles. J. Applied Stat., 32: 17-24.

Murthy, A.R.V. and R.H. Singh, 1989. Concept of prameha/madhumeha (contradictions and compromises). Ancient Sci. Life, 9: 71-79.

Philips, Z., L. Ginnelly, M. Sculpher, K. Claxton and S. Golder *et al*., 2004. Review of guidelines for good practice in decision-analytic modelling in health technology assessment. Health Technol. Assess., 8: 1-158.

Roy, C.K., J.K. Ojha and H.S. Bajpai, 1992. A review of the history of prameha and diabetes mellitus. Ancient Sci. Life, 12: 394-398.

Sargent, R.G., 2005. Verification and validation of simulation models. Proceedings of the Winter Simulation Conference, (WSC'05), IEEE Press, Piscataway, New Jersey, pp: 130-143.

Sayyad, M.G., A.K. Shahani, P.R. Harper, V.de Senna, K.M. Shelgikar and C.S. Yajnik, 2002. A system modelling approach for the care of diabetic retinopathy in India. Quantitative approaches in health care management. Proceedings of 27th Meeting of European Working Group on Operational Research Applied in Health Services, (ORAHS'02), Vienna, pp: 271-280.

Sayyad, M.G., G. Gopal and A.K. Shahani, 2011. Classification and regression trees: A possible method for creating risk groups for progression to diabetic nephropathy. J. Applied Sci., 10: 28850-28850.

Shah, M., E. Zondervan and A.B de Haan, 2010. Modelling and simulation of an unsaturated polyester process. J. Applied Sci., 10: 2551-2557.

Shahani, A.K., N. Korve, K.P. Jones and D.J. Paynton, 1994. Towards an operational model for prevention and treatment of asthma attacks. J. Operat. Res. Soc., 45: 916-926.

Shahani, A., 1996. Commentary: Models can be powerful tools for making effective decisions about effective and efficient health care. Br. Med. J., 313: 1057-1057.

Shahani, A.K., S.A. Ridley and M.S. Nielsen, 2008. Modelling patient flows as an aid to decision making for critical care capacities and organisation. Anesthesia, 63: 1074-1080.

Shalliker, J. and C. Ricketts, 2002. An Introduction to SIMUL8, Release Nine. School of Mathematics and Statistics, University of Plymouth, Plymouth, UK..

Sharma, P.V., 1981. Charaka Samhita. Vol. 4, Chaukhamba Orientalia, Varanasi, India.

Sharma, R.K. and P.S. Patki, 2010. Double-blind, placebo-controlled clinical evaluation of an Ayurvedic formulation (GlucoCare capsules) in non-insulin dependent diabetes mellitus. J. Ayurveda Integrative Med., 1: 45-51.

Sridhar, G.R., 2000. Diabetes in India: Snapshot of a panorama. Curr. Sci., 83: 791-791.

Svoboda, R.E., 1992. Ayurveda: Life, Health and Longevity. 1st Edn., Penguin Arkana, New York, USA..

Upadhayay, V.P. and K. Pandey, 1984. Ayurvedic Approach to Diabetes Mellitus and its Management by Indigenous Resources. In: Diabetes Mellitus in Developing Countries, Bajaj, J.S. (Ed.). Interprint, New Delhi, India, pp: 375-377.

Venkata Raju, B., 2007. Expert system linked to a simulation model in the expert of decision making. J. Applied Sci., 7: 1805-1808.

WHO, 2005. Preventing Chronic Diseases: A Vital Investment: WHO Global Report. World Health Organization, Geneva, Switzerland, ISBN: 9241563001.

Watkins, P.J., 1993. ABC of Diabetes. 3rd Edn., BMJ Publishing Group, London.