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One Example of Using Markov Chain Monte Carlo Method for Predicting in Medicine

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Abstract: Coronary heart disease is one of the most frequent causes of death in Ukraine. With the purpose of conducting adequate preventive work and planning the provision of specialized medical care for patients with coronary heart disease, the proposed paper predicts the prevalence of this disease in the next 10 years. The problem of prediction is solved by using Markov Chain Monte Carlo Method. An increasing of the incidence of coronary heart disease to 35041.21 per 100,000 population in 2025 is predicted.

Keywords: Coronary Heart Disease, Prediction, Epidemiology, Markov Chain, Monte Carlo Methods

1. Introduction

According to the World Health Organization, noncommunicable diseases in the XXI century have become one of the main problems for health systems, and have a negative impact on sustainable development and the socio-economic structure of the countries of the world. At the same time, they are also the most common cause of death. The first place in the structure of total mortality is stable diseases of the circulatory system, in particular CHD [1]. This group of diseases characterizes a high level of primary disability and high mortality among patients of working age and, consequently, a decrease in the life expectancy of the population. Development of heart failure, left ventricular remodeling processes, reduction of its contractile capacity and development of systolic dysfunction of the myocardium lead to a decrease in the duration and quality of life of patients. Mortality from the development of myocardial infarction remains quite high. Actually CHD is a manifestation of changes in coronary vessels characterized by the formation of an atherosclerotic plaque, its growth in the lumen of the vessel, with the narrowing of the latter. Insufficient blood supply leads to a decrease in the contractile capacity of the heart muscle, dystrophic changes in cardiomyocytes, and the expansion of connective tissue in the heart wall. The last stage of this process is erosion of the plaque with the release of its contents and thrombosis, due to the standard response of the circulatory system of the blood to the damaged vessel wall. All this leads to deep ischemia of the area of the heart muscle and its necrosis.

Therefore, the purpose of this work is to create a system for predicting the prevalence of CHD in the population, which will enable not only to predict the growth of the disease, based on the indicators of past years, but also to be able to carry out preventive measures aimed at reducing mortality and disability.

2. Predicting the Prevalence of Coronary Heart Disease

2.1. Construction of the Markov Chain of Coronary Heart Disease Prevalence in Ukraine

In medical forecasting, there are often challenges in which it is necessary to assess the risk that is continuous for a long time, and important events can occur more than once. One of the ways to solve this type of problem is to use trees, but it is difficult in medical use and may require significant

simplifications. J. R. Beck, co-authored in [2] at first time described the using of Markov models for prediction in medicine. Since that time, different authors were studying this problem [3-7].

Markov models suggest that the patient is always in one of the finite numbers of discrete states of health, called the Markov states. All events are modeled as a transition from one state to another. The time-space of analysis is divided into the level of time intervals (cycles), during which a patient with a certain probability can move from one state to another. The length of the cycle is chosen to represent a clinically significant period of time. For example, for a model that covers the entire life of a patient, the cycle may be one year. Depending on the speed of changing the patient's states, the cycle length for different models may vary within very wide limits.

In order for the Markov chain to end, it must contain at least one absorbing state from which the patient can't pass into other states. In medical models, such a condition is the death of the patient, as this is the only condition from which the patient can't escape. Usually, there is only one death state in the model, but if the model's purpose is to determine the causes of mortality, there may be several such states.

To build the Markov chain of CHD prevalence in Ukraine, let's use the following epidemiological data. According to the analysis of the incidence of coronary heart disease in Ukraine, presented in [8], in 2010, the incidence of coronary artery disease in Ukraine as a whole was 23 455.8 per 100 000 population, the incidence of coronary heart disease was 1,708.4 per 100,000 population, primary disability 3,8 per 10 000 population, mortality from CHD 687.3 per 100 000 population. The total mortality rate in Ukraine in the same year according to the population of Ukraine [9] was 1 520 per 100 000 people. For complete treatment of CHD, aortic coronary artery bypass surgery is used, which was performed in 3.8% of patients [10].

Consider the possible states of Markov chain:

H - healthy;

S - suffering from coronary heart disease;

B - CHD after aortic coronary artery bypass grafting;

I - CHD with a disability;

D - dead.

Note that a healthy person is minded relatively healthy individuals not suffering from coronary heart disease.

Consider the probabilities of transitions between possible states.

A healthy person (state H) may be healthy, get sick of a coronary heart disease, or die. Since the incidence is 1 708.4 per 100 000 people, the probability of passing one step from the state H to the state of S is

$$P_{HS}(1) = 0,017084 .$$

Since the total mortality rate is 1 520 per 100,000 people, the probability of passing one step from the state H to the state of D is

$$P_{HD}(1) = 0,0152 .$$

Then the probability of healthy people stay healthy is

$$P_{HH}(1) = 1 - 0,017084 - 0,0152 = 0,967716 .$$

A CHD patient (state S) may be ill, get a disability, be operated and move to a state after aortic coronary artery bypass, or may die. Since primary disability in CHD is 3.8 per 10 000 population, the probability of one step shift from state S to state I is

$$P_{SI}(1) = 0,00038 .$$

3.8% of patients carry out aortic-coronary bypass surgery, so the probability of transition from state S to state B

$$P_{SB}(1) = 0,038 .$$

Since mortality of patients with CHD is 687.3 per 100 000 population, and the incidence of coronary heart disease in Ukraine as a whole was 23 455.8 per 100 000 population, the probability of a patient dying from CHD is 0.029302. In addition, the patient may die for another reason, and the total mortality rate is 1 520 per 100 000 people, so the probability of one step from state S to state D equals

$$P_{SD}(1) = 0,044502 .$$

Then the probability of a patient with CHD remaining in the state S is equal

$$P_{SS}(1) = 0,917118 .$$

A coronary artery disease patient after aortic coronary artery bypass (state B) may remain in the same state, return to state S or die. However, aortic-coronary bypass surgery does not exclude the possibility of developing atherosclerotic lesions in other parts of the coronary vessels, and, on the contrary, the development of angina attacks or the development of myocardial infarction. Therefore, the probability of returning to the state S, as well as from the state of H, is equal to

$$P_{BS}(1) = 0,017084$$

Just as from the H state, the probability of death is equal to

$$P_{BD}(1) = 0,0152 .$$

Then the probability of remaining in the state B is equal

$$P_{BB}(1) = 0,966716 .$$

A person with CHD with a disability (state I) may remain in the same condition, move to a state after aortic coronary artery bypass or die. Similar to the state S, the probability of death is equal to

$$P_{ID}(1) = 0,044502,$$

and the probability that the patient will make aorta-coronary bypass surgery is equal to

$$P_{IB}(1) = 0,038.$$

Then the probability of remaining in the state *I* equals

$$P_{II}(1) = 0,917498.$$

State *D* (dead) is absorbent, it is impossible to get out of it, therefore $P_{DD}(1) = 1$.

According to the above considerations, the matrix of transition probabilities is following

$$P(1) = \begin{bmatrix} 0,967716 & 0,017084 & 0 & 0 & 0,0152 \\ 0 & 0,917118 & 0,038 & 0,00038 & 0,044502 \\ 0 & 0,01784 & 0,966716 & 0 & 0,0152 \\ 0 & 0 & 0,038 & 0,917498 & 0,044502 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Then the Markov chain for patients with CHD will have the form that is presented in Figure 1.

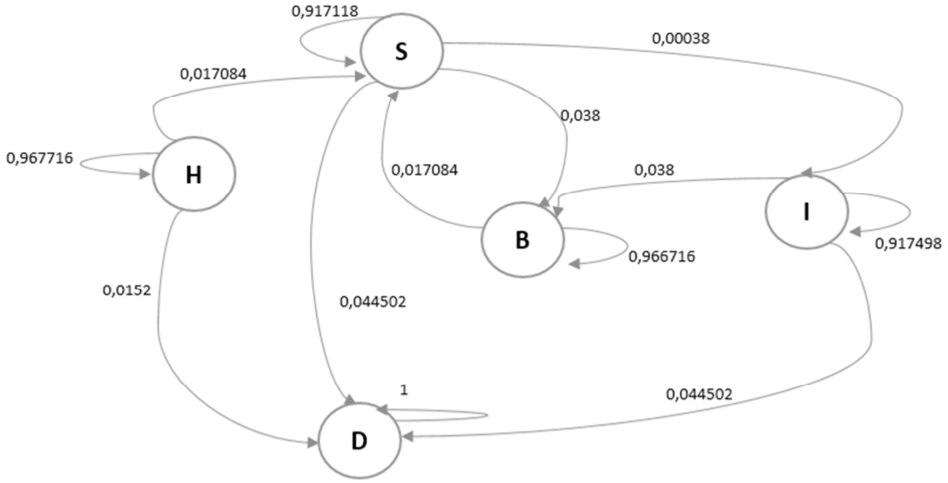

Figure 1. *Markov chain for patients with coronary heart disease.*

Consider a more detailed Markov chain. State *H*. State *H* is non-recurrent, since one can come into the state *H* only from the state *H*. The states *S* and *B* are connected, since state *B* can reach state *B*, and from state *B* it is possible to reach state *S*. The states *S* and *I* are also related, since from the state *S* one can come to state *I*, and from state *I* it is possible to arrive at the state *B* from which it is possible to arrive in state *S*. The states *H*, *S*, *B*, *I* are insignificant. From each state you can come to the state *D*, which is not possible to return from. The state *D* is significant and nonzero.

2.2. Forecasting the Prevalence of Coronary Heart Disease

To predict the prevalence of CHD, the Monte Carlo method for Markov chains is used. The model is constructed since 1996. The result of forecasting is compared with known epidemiological data.

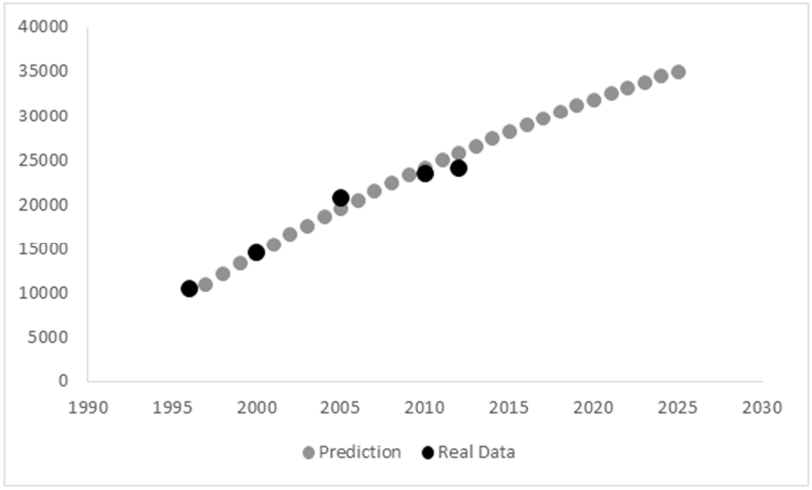

Figure 2. *Prediction of CHD prevalence.*

The population of Ukraine in 1996 amounted to 51 060 000 people. The prevalence of coronary heart disease in 1996 was 10594.2 per 100 000 people, that is, patients with CHD were 5409399 people. Consider two possible initial states H and S with probabilities $p_H = 0,894058$ and $p_S = 0,105942$. Figure 2 shows a comparison of the prevalence of CHD predicted by MCMC and the actual incidence of coronary heart disease, which was presented in [11]. The average forecast error is 3.24%.

Consequently, an increasing in the incidence of CHD to 35041.21 per 100 000 population in 2025 is forecasted. Note that in 2016 [11] a similar forecast of the growth of CHD prevalence in Ukraine was raised by 63.6% in 2025 compared to 2014.

Many different factors play the role in the development of CHD. Some of these factors are modified (lifestyle, alcohol, smoking, overweight), other are unchanged (age, gender, genetic predisposition). The task of doctors is not only the treatment of established CHD, but also preventive work with patients and healthy people with an increased risk of developing the disease. Combining the efforts of the doctor and the patient makes possible successful treatment of the disease and prevents its occurrence and progression. For the effective work of doctors and health care institutions, it is necessary not only accurate prediction of the prevalence of CHD among the population, but also the structural distribution of subspecies of this pathology. The proposed in the paper prognosis will help correctly calculate the amount of qualified health care needed by trained medical personnel, the number of medications and interventions needed to reduce mortality and social costs.

3. Conclusion

Using of the Monte Carlo Markov Chains method in medical forecasting makes it possible to predict the prevalence of non-communicable diseases in the future and, through this, to carry out adequate preventive work and planning for the provision of specialized medical care for the relevant nosology.

The prevalence of coronary heart disease in Ukraine is expected to increase to 35041.21 per 100 000 population in 2025.

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