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# Design of Health State Transition Model Based on the Specific Health Checkup Using Binary Expression

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**Abstract:** In Japan, the Specific Health Checkup program, which focuses on metabolic syndrome and aims to prevent lifestyle-related diseases, has been conducted since April 2008. We constructed state transition models of medical examination data from a sample of 3,949 subjects in Japan who received health examinations for two consecutive years. Each of the four inspection factors (body type, blood sugar, lipids, and blood pressure) was expressed as a binary variable using reference values in the Specific Health Checkup, yielding 16 health condition states, (0000) through (1111). First, we calculated state transition probabilities for each of the following three age groups: 40–49 years, 50–59 years, and 60–65 years (256 transitions  $\times$  4 age ranges). We then constructed a health state-transition model using two cubic lattices with eight vertices for each of the age groups, and compared these models. In the state transition model for the age group 40–49 years, we found that patients demonstrated a tendency to transition to a healthier state when one of the three factors, other than body type, exceeded the reference range. In addition, transition out of metabolic syndrome required that the three factors other than body type fell within the reference range prior to transition. The health state transition model provides an easy visual demonstration of the health state of the examinee, as well as indicating the direction of the state transition. We believe that our health state transition model provides guidance for efficient and effective health maintenance and improvement for each age group.

**Keywords:** *Metabolic syndrome, The Specific Health Checkup, Transition model, Health states*

## 1. INTRODUCTION

In Japan, the Specific Health Checkup program, focusing on metabolic syndrome, has been conducted since April 2008 with the goal of preventing lifestyle-related diseases [1]. Following the proposal of the Data Health Plan in 2014, the healthcare business sector in Japan was promoted under the framework of this plan, and the Specific Health Checkup and Specific Health Guidance have become the pillars of specific healthcare businesses.

We have been working on the construction of a risk assessment system based on a Bayesian network approach, which includes tests and interviews in accordance with the framework and data structure of the Specific Health Checkup [2-4]. Moreover, we have been working on the development of a sustainable health support system between medical examinations taken every other year. To provide individual health guidance to medical check-up examinees, we believed that it was necessary to clearly express the health state to which they are likely to transition in future.

To date, research on the results of medical examinations

and the relationship between health guidance and the stage of behavioral change achieved, as well as research and development of tools to visually represent the transition of medical examination results using self-organizing maps, have been performed using the behavioral change stage model, which is one of the theoretical foundations of the Specific Health Checkup [5-7]. While these studies are valuable to researchers, they have proved difficult for examinees to understand. Therefore, we propose a transition model that can be used to represent the health status of different patients in various rational ways.

In the present study, we propose a rational method of health state representation using paired medical examination data from two consecutive years, and construct a state transition model based on the suggested causal relationship between metabolic syndrome and the health-related inspection factors tested by the Specific Health Checkup. We then show the effectiveness of our proposed model by examining the tendency for health status transition based on health checkup results, using the state transition model constructed for each age group.

2. METHOD

In this study, non-linkable anonymized medical examination data for 3,949 patients were collected from a certain business establishment for two consecutive years. From research reports on factor analysis of conventional metabolic syndrome, the following factors are known to contribute to the development of metabolic syndrome: (1) abdominal circumference and body mass index (BMI) (body type factor), (2) fasting blood glucose and hemoglobin A1c (HbA1c) (blood glucose factor), (3) neutral fat and high-density lipoprotein (HDL) cholesterol (lipid factor), and (4) each pair of systolic and diastolic blood pressures (blood pressure factor) [8,9]. Therefore, by taking the logical addition of the binarized test items for each factor pair and setting the bits for each factor, all test data can be expressed using the four factors of body type, blood glucose, lipid, and blood pressure. We devised a strategy to express each factor in 16 states from (0000) to (1111) and called this process 4-bit representation of “16 health states” (Fig.1).

The examinees were initially classified into one of the 16 health states based on the test data in the year they received the medical examination, and they were subsequently classified into any of the 16 states based on the test data in their medical examination from the following year. The total number of possible state transitions was thus  $16 \times 16 = 256$ . We classified 3,949 examinees, grouped by age, into each of the 16 health states, clarified the number of state transitions among the examinees, and constructed a state transition table. We thereafter constructed a state transition probability table by calculating the state transition probability of each of the 256 transitions from this state transition table. An example list of calculated state transition probabilities for the 256 possible state transitions is shown in Table 1.

Next, as a method of visualizing the transitions of the 16 health states, we proposed a health state transition model which expresses the transitions between health states in terms of movement between the vertices of a cubic lattice. As stated above, the number of possible health states was 16 when the four factors (i.e., body type, blood glucose, lipid, and blood pressure) of the test data were expressed in 4 bits. If we divide the 16 states in half and consider them as two sets comprising eight states each, we can express the 16 states using two cubic lattices with eight vertices. Therefore, if we consider the 256 possible state transitions as the movement between the vertices of these two cubic lattices, it becomes possible to express them with a dynamic model that is easy to understand and

visualize. We called this a “health state transition model represented by a cubic lattice” and proposed it as a new method for analyzing and expressing medical examination data.

In the context of the Specific Health Checkup, we thought it desirable to divide the 16 states into two broad categories based on body type, with health state transitions within each body type represented by a separate cubic lattice. Movement between vertices, which indicates transition between states, is indicated by an arrow, and a certain state transition probability is used as a threshold to determine whether the arrow should be displayed. In this way, we can construct a health state transition model that represents the trend of major health state transitions among patients. In this study, 3,949 examinees were divided into the following three age groups: 40–49 years, 50–59 years, and 60–65 years, and a health state transition model for each age group was constructed using a state transition probability of 10% as a threshold. We subsequently performed comparisons and examinations using the models for different age groups.

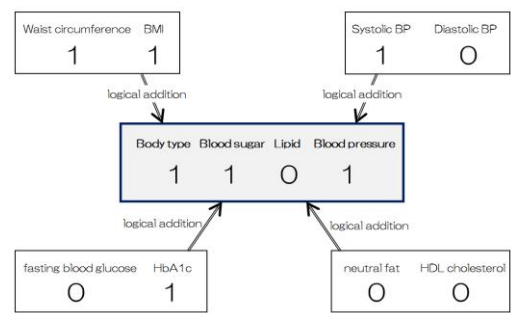


Figure 1: An example of process 4-bit representation of "16 health states"

Table 1: An example of a list of 256 calculated state transition probabilities.

	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
0000	0.68	0.07	0.05	0.01	0.11	0.00	0.01	0.00	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00
0001	0.34	0.41	0.00	0.05	0.01	0.05	0.00	0.00	0.04	0.06	0.00	0.01	0.01	0.01	0.00	0.01
0010	0.21	0.03	0.46	0.09	0.03	0.00	0.07	0.03	0.03	0.00	0.07	0.00	0.00	0.00	0.00	0.00
0011	0.10	0.16	0.06	0.32	0.03	0.00	0.06	0.03	0.03	0.00	0.03	0.10	0.00	0.00	0.00	0.06
0100	0.34	0.04	0.02	0.00	0.40	0.06	0.04	0.01	0.02	0.01	0.01	0.01	0.03	0.01	0.01	0.01
0101	0.11	0.18	0.02	0.02	0.11	0.40	0.02	0.05	0.02	0.00	0.00	0.03	0.02	0.05	0.00	0.00
0110	0.17	0.00	0.07	0.00	0.13	0.10	0.30	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.03	0.07
0111	0.00	0.00	0.15	0.00	0.08	0.31	0.23	0.08	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.08
1000	0.14	0.02	0.02	0.00	0.01	0.01	0.00	0.00	0.46	0.11	0.09	0.02	0.09	0.01	0.02	0.00
1001	0.05	0.13	0.00	0.00	0.01	0.01	0.00	0.00	0.15	0.35	0.02	0.14	0.02	0.08	0.01	0.01
1010	0.06	0.03	0.07	0.00	0.00	0.00	0.01	0.00	0.14	0.02	0.43	0.08	0.03	0.03	0.11	0.02
1011	0.01	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.06	0.16	0.18	0.33	0.01	0.06	0.04	0.11
1100	0.03	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.19	0.04	0.01	0.00	0.27	0.19	0.15	0.03
1101	0.00	0.03	0.00	0.00	0.04	0.05	0.00	0.01	0.05	0.13	0.00	0.03	0.13	0.43	0.06	0.04
1110	0.03	0.00	0.01	0.00	0.03	0.00	0.01	0.00	0.07	0.06	0.04	0.00	0.10	0.06	0.52	0.06
1111	0.01	0.03	0.00	0.00	0.03	0.04	0.03	0.03	0.03	0.04	0.04	0.12	0.04	0.07	0.11	0.40

3. RESULTS AND DISCUSSION

Figure 2 shows a health state transition model using data from a total of 3,949 subjects. In this model diagram, the left cubic lattice represents the eight states of the body type factor 1 that represents overweightness/obesity, and the right cubic lattice represents the eight states of the body type factor 0 that represents healthy BMI/ideal weight. When the health state of the examinee, as measured by medical examination results, falls into cubic lattice on the left, he/she is in a state of metabolic syndrome. The (1111) state of the vertex, shown in red, represents the least favorable health outcome for the patient, in which all four inspection factors have a value of 1 (representing the unhealthy state). Conversely, the (0000) state of the vertex, shown in blue, represents the ideal health outcome, with all four factors equal to 0 (representing the healthy state). The transition probability threshold between the states indicated by the vertices of the cubic lattice is set to 0.1. The direction of state transitions whose transition probability exceeds this threshold is indicated by an arrow, with the probability value shown beside it. Blue arrows indicate improvement in health status while red arrows represent deterioration in health status, and black arrows depict stability in health status. The arrow from the left cubic lattice (body type factor 1) to the right cubic lattice (body type factor 0) indicates a break from metabolic syndrome.

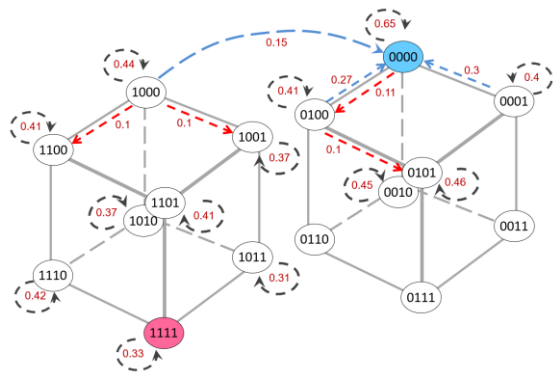


Figure 2: A health state transition model using data from a total of 3,949 subjects

Health state transition model diagrams for the 40–49 years age group and the 60–65 years age group are shown as examples in Fig. 3 and Fig. 4, respectively.

In the health state transition model for the 40–49 years age group, as shown in Fig. 3, patients demonstrated a high probability of improving to a more favorable health condition when only one factor, other than body type,

exceeded the reference range. In addition, the model contains only one arrow that crosses the left and right cubic lattices from the (1000) state to the (0000) state. This implies that the transition out of metabolic syndrome requires that all three factors other than body type fall within the reference range prior to transition.

The 50–59 years age group showed the same tendency for transition out of metabolic syndrome as the 40–49 years age group; however, in this model there was a tendency for factors other than the body type factor to switch easily between the normal and non-standard values.

In the 60–65 years age group, shown in Fig. 4, bidirectional switching between states occurred randomly, and there was no characteristic tendency. This observation indicates that the health status of patients in their fifties and sixties can easily change from favorable to unfavorable, or from a healthy to an unhealthy state. This suggests that there is a need for continuous health guidance for people in this age bracket to help them maintain their good health, and, after an improvement has been observed, to avoid health deterioration in the future.

In addition, in all age groups, with the exception of the arrow that crosses between the left and right cubic lattices, all state transition arrows occurred within the left or right lattice, and transitions that deviated from their respective lattice [for example, the (1101) state → the (1000) state] were not seen. In the criterion of transition probability threshold of 0.1 indicates that there is only one factor state transition occurs.

Our results suggest that it is possible to construct a system that provides health guidance and support to examinees, based on their current health status, for future health and life improvement.

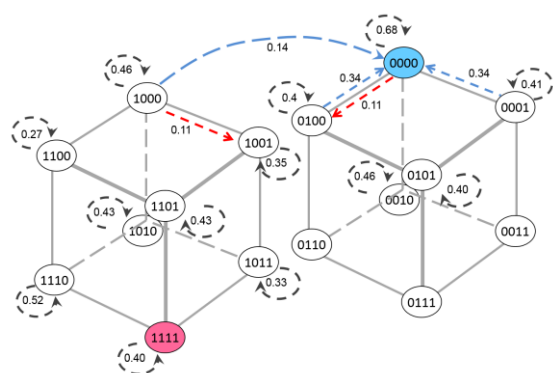
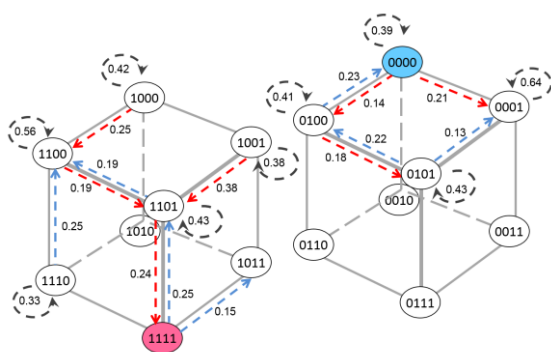


Figure 3: The health transition model for the 40–49 years age group



**Figure 4:** The health transition model for the 60–65 years age group

#### 4. CONCLUSION

In the present study, we proposed a health state transition model. We constructed a health state transition model for each age group analyzed in the study, performed a comparison between these models, and demonstrated that models of this type provide a useful and easily understandable method of visualizing and predicting health state transitions.

The health state transition model can be used as a convenient visual indicator of the current health status of an examinee, as well as indicating the direction probability of future health state transitions. We thus believe it to be a promising model for health state transition analysis.

It is expected that the health state transition model and health guidance based on the results of this analysis, as well as awareness of the age-related and health state trends depicted by these models, will lead to efficient and effective health maintenance and improvement.

#### ACKNOWLEDGMENTS

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