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Fuzzy Dependency Analysis for Medical Checkup Reference

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***Abstract*— We investigate dependency of human health condition evaluation on changing medical checkup reference. In our previous paper, we proposed an evaluation method based on fuzzy set for health checkup data. This method converted health checkup data into fuzzy degree to operate a multivariate data analysis. The obtained fuzzy degree was considered as an attribute value in closed interval [0, 1]. Total health indices which are defined by operation of the fuzzy degrees are treated as the same scale. In this paper, to investigate fuzzy normal degrees by changing to new reference interval, we visualized health changes by calculating the total health indices using our proposed method. As the result, we succeeded in visualizing health change, and confirmed quantitatively that disease patients decrease by changing to new reference interval.**

***Index Terms*—Fuzzy logic, Lifestyle disease, Medical checkup data, Diagnostic criteria, Reference interval**

I. Introduction

Recently, lifestyle diseases have become serious problem in developed countries [1], [2]. The lifestyle diseases cause cardiovascular troubles such as cerebral accident, cardiac infarction. According to world health statistics in 2012 by World Health Organization (WHO), about 57 million people died in 2008. In it, about 36 million people died of lifestyle diseases such as diabetes, hypertension and dyslipidemia [2], [3]. Most of lifestyle diseases are caused by unhealthy lifestyle. Therefore an individual can prevent it by taking moderate exercise, good eating habits, prohibition of smoking and others [1], [4]. To support health management, a life-log service is provided via internet or mobile device. Furthermore, local governments carry out health diagnosis and the health guidance in Japan. These health data have complex features. It is difficult for us to correctly understand these data. Furthermore, it is more difficult for us to evaluate total status of our health from the data. In general, physicians synthetically evaluate state of health from their health data, and give advice to manage their life. To establish a framework to evaluate medical checkup data consisting on various domains, we proposed a fuzzy calculation method [5].

In Fuzzy set [6], it is possible to treat ambiguous information by interval [0, 1]. Health data includes ambiguity because of measurement accuracy and environment. They classified into one of two large groups of healthy and unhealthy. Fuzzy degree is used for expressing health degree. The fuzzy logic can convert the health data to the fuzzy degrees of normality. By using the degree, we have proposed a calculation method of a total index to evaluate our health condition.

This paper describes a computational framework for diagnosing health checkup data by fuzzy logic. We visualize human health state using health indices based on fuzzy logic. We express health human state to numeric; therefore we convert health data into fuzzy degrees by our proposed method. In this method, health and disease conditions are represented unified indices called fuzzy normal degree. Then, we compare with all health indices as the same scale. In our study, we employ new diagnostic criteria made from new reference interval in 2014 and current diagnostic criteria used in 2013. We define fuzzy membership functions from the new diagnostic criteria. By expressing health conditions quantitatively, fuzzy degrees enabled us to visualize health change according to both reference. As the result, we confirmed that the fuzzy normal degrees of disease patients decreased by changing new reference intervals.

II. Japanese Medical Checkup

In Japan, anyone have an opportunity to receive medical checkup once a year at least. For example, conducting an annual medical checkup for all pupils and students is compulsory, and businessmen have a duty to make employee undergo regular medical checkup. Regular medical checkup carried out to find illness and suspicion of it. Like this, Japanese people ought to be able to grasp state of their health. However, the number of patients of lifestyle diseases and deaths caused by them increase in people of 40 years old or more. The lifestyle diseases are not only the biggest disincentive of the health and longevity but also have a big influence on national medical expenses. Therefore, the Ministry of Health, Labour and Welfare (MHLW) is promoting lifestyle diseases prevention in Japan.

MHLW carries out special medical checkup for the purpose of preventing and treating for lifestyle diseases since April 2008 in Japan. The principal purposes of this medical checkup are prevention and treatment for the metabolic syndrome, the syndrome is a cause of major lifestyle diseases. The special medical checkup conducts for all public medical insurance

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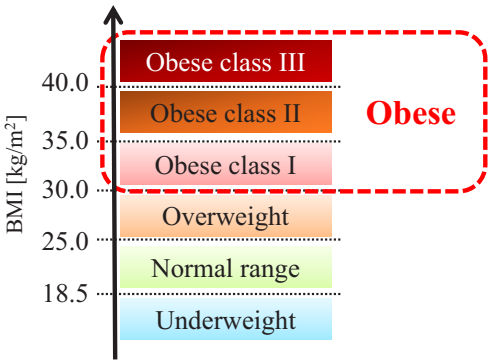


Fig. 1. BMI classification

member of between ages of 40 and 74 years old. Medical checkup is made up many inspection items. Unlike the regular checkup, the special checkup is carried out for putting emphasis on obesity by inspecting LDL cholesterol and ventral girth. Inspection items of medical checkup have unique characteristics. We have to evaluate each state of our medical checkup result by ourselves. For example, BMI classification is shown Fig. 1. Figure 1 shows that our health conditions about BMI are evaluated as one of six states. We can know whether we are obesity by ourselves from our BMI values. However, it is difficult to get information about lifestyle diseases and management to our life by ourselves.

III. Fuzzy Logic for Health Data

This section describes fuzzy set for evaluating medical checkup data. Fuzzy degrees for medical checkup data present normality of health condition. We call this fuzzy normal degree. The higher degree demonstrates normal conditions and lower degree does abnormal ones. The fuzzy degree is obtained from each inspection item. In our study, we define fuzzy membership functions from diagnostic criteria of medical checkup [6-8].

A. Fuzzy Normal Degree

In our study, we proposed an analysis method based on fuzzy logic for medical checkup data. Fuzzy normal degree is considered as an attribute value in closed interval [0, 1]. To convert health data, state of health is defined that quite healthy is 1.0, and unhealthy is 0.0. We treat the fuzzy degree as an unified evaluation index. In the proposed method, fuzzy membership functions made from health diagnostic criteria of Japanese Society of Human Dry Dock used in 2013 [9]. In our study, we use twelve health data: body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), triglyceride (TG), high-density lipoprotein cholesterol (HDL), low-density lipoprotein cholesterol (LDL), serum glutamic-oxaloacetic transaminase (GOT), serum glutamate pyruvate transaminase (GPT), gamma-glutamyl trans peptidase (GTP), glycated hemoglobin A1c (HbA1c), creatinine (CRE) and uric acid (UA). Each inspection item establishes diagnostic criteria. The criteria occupies by four standard divisions. The division "A" is no problem. The division "B" is abnormality a little. The divisions "C" and "D" are abnormal. Therefore, improvement is necessary in "C" and "D". Thus, when a medical checkup data belongs to "C" or "D", it is necessary to take 2nd health check in order to check some disease.

TABLE I. New reference interval

Inspection item	Male	Female
BMI [kg/m^2]	18.5-27.7	16.8-26.1
SBP [mmHg]	88-147	
DBP [mmHg]	51-94	
TG [mg/dl]	39-198	32-134
HDL [mg/dl]	40-92	49-106
LDL [mg/dl]	72-178	73-183
GOT [U/L]	13-29	12-24
GPT [U/L]	10-37	8-25
GTP [IU/L]	12-84	9-40
HbA1c [%]	4.63-5.67	4.62-5.67
CRE[mg/dl]	0.66-1.08	0.47-0.82
UA [mg/dl]	3.6-7.9	2.6-5.9

In April 2014, Japanese Society of Human Dry Duck has reported about new reference intervals [9]. They studied to make the reference intervals for medical checkup data in all medical examination institutes. Their study is mega-study for 1.5 million subjects, and they made new reference intervals based on a standard of the Clinical Laboratory Standard Institute (CLSI). The intervals show normal subjects. Thus, intervals about abnormal subjects do not be stated clearly in these intervals. The intervals show Table I. As shown Table I, the intervals of almost inspection items are distributed in gender. In this paper, we define fuzzy membership functions using the new reference intervals. To decide unhealthy, we employed current abnormal diagnostic criteria. We form new diagnostic criteria by incorporating new reference intervals to ones. Table II shows the new diagnostic criteria. In the criteria, the divisions "A" of current reference intervals are extended by incorporating new reference intervals. We defined fuzzy membership functions based on Table II. Fuzzy membership functions $Standard_{Item}$ are defined each inspection item by Fig. 2. The fuzzy membership functions are divided to six patterns shown in Table II. In every pattern, the membership functions are made from polygonal line. Vertexes of the functions are set as boundary of standard division as shown in Table II. In pattern 1, new reference intervals have lower limits. Therefore, we take 0.5 for the degree that an inspection value is 0.0, and connect the point with a lower limit point of division "A" by straight line. Fuzzy degrees of each boundary with divisions are shown in Table III. Thus, fuzzy degrees in "C" are lower than 0.5, and that in "D" is always 0.0. In the division "A" and "B", we obtained higher fuzzy degree than 0.5. Thus, defined fuzzy membership functions express decision new diagnostic criteria.

Fuzzy degree $\mu_{Item}(Item(x))$ is defined by Equation 1.

$$\mu_{Item}\left(Item\left(x\right)\right) = \min\left(Standard_{Item}, S_{Item(x)}\left(Item\right)\right) \quad (1)$$

Here, the notation *Item* denotes an index of inspection item. The notation $Item(x)$ denotes a value of the *Item*, and the notation x does an examinee of the health check. The notation $S_{Item(x)}(Item)$ is fuzzy singleton function, which is defined by Equation 2.

TABLE II. NEW DIAGNOSTIC CRITERIA

Inspection item	Gender (M / F)	Division and range of value				Function Pattern
		A	*B*	*C*	*D*	
BMI [kg/m^2]	M	18.5-27.7		-18.4, 27.8-		2
	F	16.8-26.1		-16.7, 26.2-		2
SBP [mmHg]	M / F	88-147		147-159	160-	3
DBP [mmHg]	M / F	51-94		95-99	100-	3
TG [mg/dl]	M	39-198		199-399	-38, 400-	6
	F	32-134	135-199	200-399	-31, 400-	5
HDL [mg/dl]	M	40-92		30-39, 93-119	-29, 120-	4
	F	49-106		30-48, 106-119	-29, 120-	4
LDL [mg/dl]	M	72-178		60-71, 178-179	-59, 180-	4
	F	73-183		-72, 184-		2
GOT [U/L]	M	13-29	30-35	36-50	51-	1
	F	13-28	29-35	36-50	51-	1
GPT [U/L]	M	10-37	38-40	41-50	51-	1
	F	8-25	26-40	41-50	51-	1
GTP [IU/L]	M	12-84		85-100	101-	3
	F	8-25	26-80	81-100	101-	1
HbA1c [%]	M	4.63-5.67		5.68-6.12	6.12-	3
	F	4.62-5.67		5.68-6.12	6.12-	3
CRE [mg/dl]	M	0.66-1.08	1.08-1.09	1.10-1.29	1.30-	1
	F	0.47-0.82		0.83-0.99	1.00-	3
UA [mg/dl]	M	3.6-7.9		-3.5, 7.9-8.9	9.0-	3
	F	2.6-5.9	6.0-7.5	-2.5, 7.5-8.9	9.0-	1

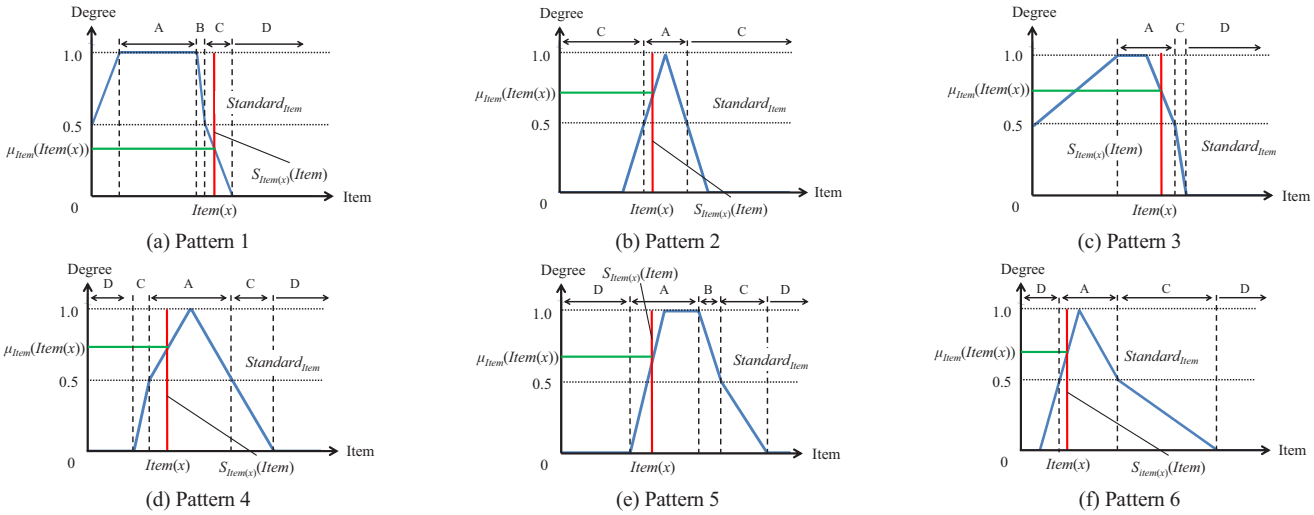


Fig. 2. Fuzzy membership functions

$$S_{Item(x)}(Item) = \begin{cases} 1 & if\ Item = Item(x) \\ 0 & otherwise \end{cases} \quad (2)$$

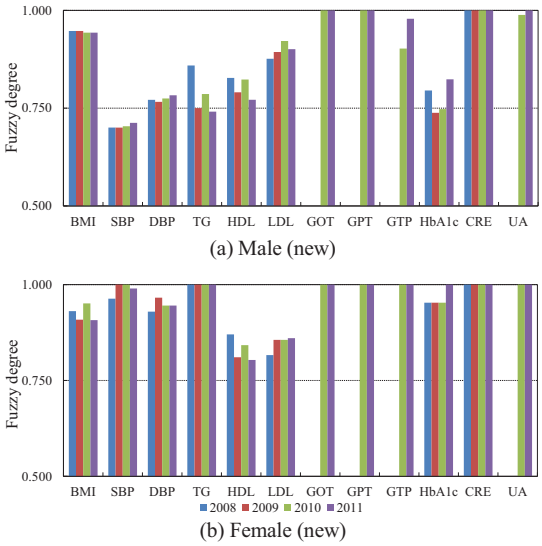
The fuzzy degree ranged from 0.0 to 1.0. We define that the fuzzy degrees being less than 0.5 is abnormal, and that being more than 0.5 is as normal. The fuzzy normal degree shows a unified evaluation index of health data.

B. Total Health Indices

Total health indices are defined by operation of the fuzzy normal degrees. At first, we define overall index which is mean of fuzzy normal degrees of twelve inspections items. Secondly, we develop disease indices which are calculated as a minimum value of fuzzy normal degrees. In this paper, we make the indices of obesity and hyperlipidemia as disease indices. In general, the obesity is related to TG and BMI, and the

TABLE III. FUZZY DEGREE OF BOUNDARY WITH DIVISIONS

Divisions		Fuzzy degree
A	B	1.0
A	C	0.5
B	C	0.5
A	D	0.0
C	D	0.0



(a) Male (new)

(b) Female (new)

Fig. 3. Degrees of each inspection items

hyperlipidemia is related to TG, HDL and LDL. We define an obesity index by Equation 3.

$$Obs = \min\left(\mu_{BMI}, \mu_{TG}\right) \tag{3}$$

Here, the notation μ_{TG} and μ_{BMI} are fuzzy degrees of TG and BMI, respectively. In a similar way, we define a hyperlipidemia index by Equation 4.

$$HL = \min\left(\mu_{TG}, \mu_{HDL}, \mu_{LDL}\right) \tag{4}$$

Here, the notation μ_{HDL} and μ_{LDL} are fuzzy degrees of HDL, and LDL, respectively. The higher disease index is evaluated better condition. These total health indices enable us to compare various health states.

IV. Experimental Result

This section describes experimental result in Japan. In our study, we used National Health and Nutrition Survey which MHLW reported from 2008 through 2011. Results of the survey publish as frequency distribution data on the website of MHLW. These data consist of results of separating by gender and age class, and include the mean and standard deviation. The composition of the number of people was different. These data excluded persons who are taking medicine and injecting to reduce inspection value.

We converted mean of Japanese health data into fuzzy degrees. Figure 3 shows these fuzzy degrees of each year. By converting the health data into the fuzzy degree, it is easy for us to understand good and bad attributes from Fig. 3. Fig. 3 suggested that Japanese males are not good SBP. In addition, LDL of females was worse than that of males, and it shows tendency to improve year by year.

Table IV shows current diagnostic criteria which Japanese Society of Human Dry Dock uses for evaluation medical checkup data in 2013. Same as Section III, we made fuzzy membership functions based on the intervals, and converted health data into fuzzy degrees by the fuzzy membership functions. Furthermore, we calculated total health indices about each in current and new diagnostic criteria by Equations 3 and

TABLE IV. Current Diagnostic Criteria

Inspection item	Division and range of value			
	A	***B***	***C***	***D***
BMI [kg/m^2]	18.5-24.9		-18.4, 25.0-	
SBP [mmHg]	-129	130-139	140-159	160-
DBP [mmHg]	-84	85-90	90-99	100-
TG [mg/dl]	30-149	150-199	200-399	-29, 400-
HDL [mg/dl]	40-119		30-39	-29, 120-
LDL [mg/dl]	60-119	120-139	140-179	-59, 180-
GOT [U/L]	0-30	31-35	36-50	51-
GPT [U/L]	0-30	31-40	41-50	51-
GTP [IU/L]	0-50	51-80	81-100	101-
HbA1c [%]	-5.1	5.2-5.4	5.5-6.0	6.1
CRE(M)[mg/dL]	-1.00	1.01-1.09	1.10-1.29	1.30-
CRE(F)[mg/dL]	-0.70	0.71-0.79	0.80-0.99	1.00-
UA [mg/dl]	2.1-7.0	7.1-7.5	-2.0, 7.6-8.9	9.0-

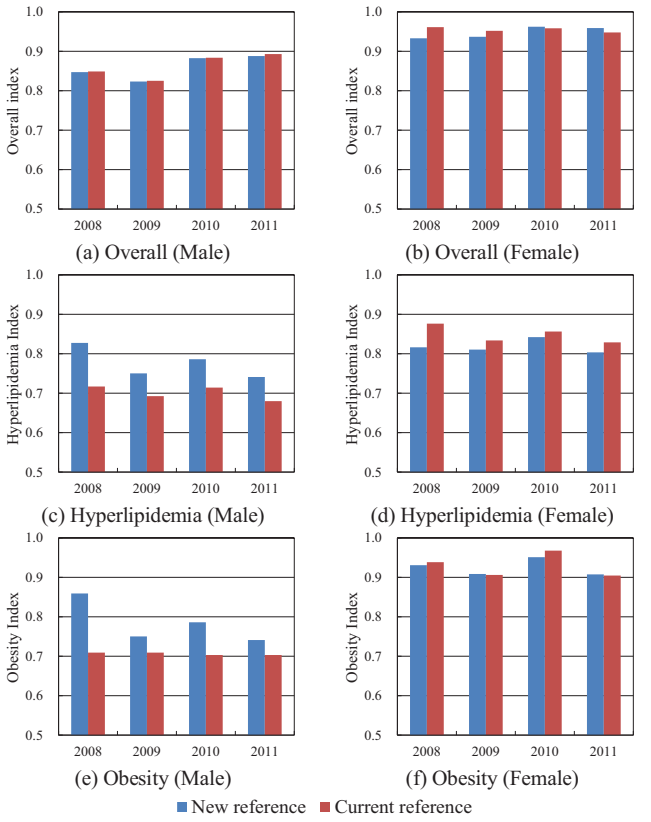
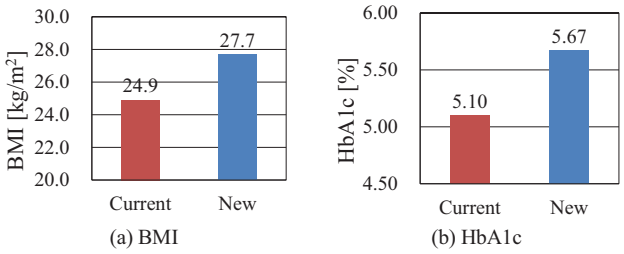


Fig. 4. Comparison total health indices

4. Results of comparison to total health indices show Fig. 4. From this figure, we can visualize the health changes by change of reference intervals due to the total health indices by fuzzy logic. Disease indices of males decrease, however hyperlipidemia indices of females increase. In addition, the overall indices hardly changed by changing to new reference intervals. In this result, we consider that lifestyle disease patients will decrease by the changing to new reference intervals. Figure 5 shows new and current references of BMI and HbA1c. The references of these items extend by changing to new reference intervals. We cannot compare the dependence



(a) BMI (b) HbA1c

Fig. 5. Reference of BMI and HbA1c

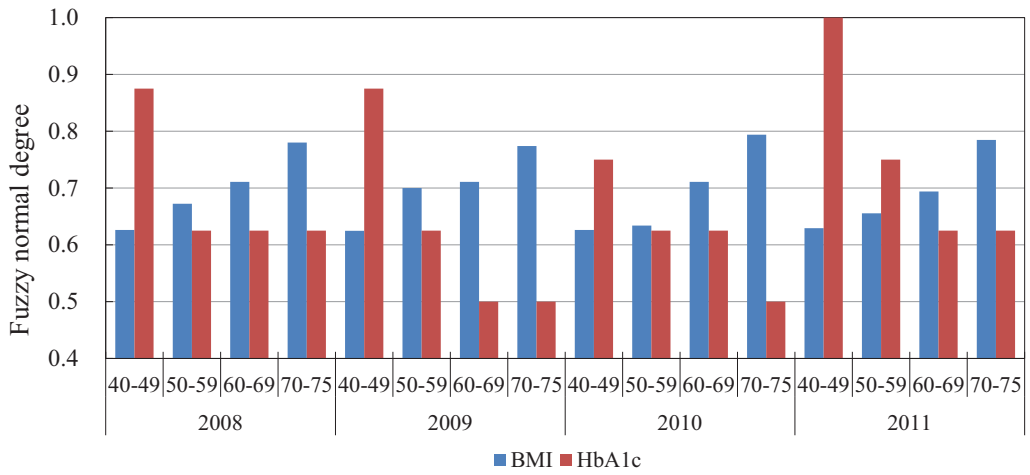
for reference of the inspection value. Figure 6 shows fuzzy normal degrees of BMI and HbA1c using current and new reference intervals. From this, BMI and HbA1c improved by changing to new references. Furthermore, it is easy for us to compare dependence of health data by changing reference intervals. By changing to new references, we confirmed that the dependence of BMI is greater than that of HbA1c by comparing the fuzzy normal degrees.

V. Discussions

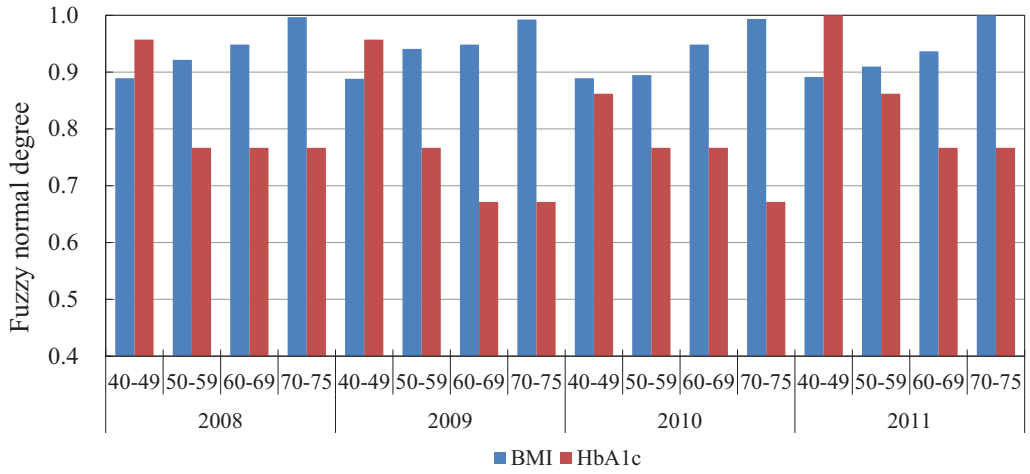
In this paper, we made new diagnostic criteria by employing new reference intervals. We compared total health indices of current diagnostic criteria and new ones. Figure 7 shows indices changes in each year by changing to new reference intervals. From this figure, we confirmed that overall indices and health indices of female hardly changed. In general, most diagnostic criteria are established based on inspection results of males. Therefore, the degrees of female should be high necessarily by using current diagnostic criteria. On the other hand, new diagnostic criteria are divided by gender. By expansion of the reference intervals, we expected to improve the fuzzy normal degrees. Therefore, we consider that normal female subjects increase by changing to new reference intervals. In addition, disease indices of males improve. By changing reference intervals, obesity indices improved higher than hyperlipidemia indices in 2008 and 2010. However the results turned over in 2009 and 2011. By visualizing the health change, it is easy for us to discover dependence on references about medical checkup data in each year.

VI. Conclusions

This paper described a visualization analysis of health change based on fuzzy logic for investigating health change by changing reference intervals. We established new diagnostic criteria by new reference intervals. Fuzzy membership



(a) Current reference



(b) New reference

Fig. 6. Comparison of fuzzy normal degrees of BMI and HbA1c (Male)

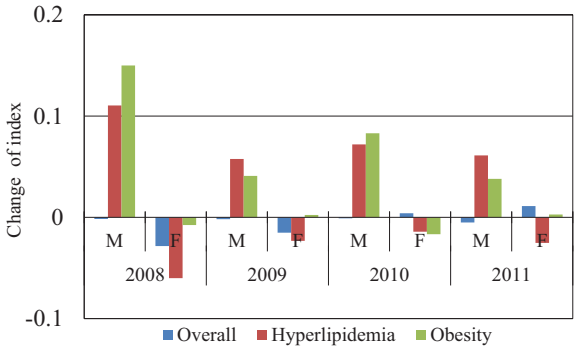


Fig. 7. Improvement of the total health indices

functions can express decision diagnostic criteria of medical feature; we converted health data into a unified evaluation index. The total health indices express health conditions, and that enable to compare with all health indices as the same scale. We visualized health data dependency on reference by the total health indices, and checked health change when the diagnostic criteria are changed. In this result, we confirmed that disease indices improved before changing intervals. However, overall index of both male and female did not change. In addition, we confirmed the improvements of degrees due to changing new reference intervals. Therefore, we consider that normal subjects increase and disease patients decrease.

Furthermore, the new reference intervals were reported by the study for modern people. Thus, diagnostic criteria should be established depending on environmental and time changes. In the future, the diagnostic criteria may be changed substantially.

In the future, we will apply this method for various diagnostic criteria of different medical examination institutes, and research the health influence by diagnostic criteria change.

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