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The development and implementation of stroke risk prediction model in National Health Insurance Service's personal health record

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ABSTRACT

Background and objective: The purpose of this study was to build a 10-year stroke prediction model and categorize a probability of stroke using the Korean national health examination data. Then it intended to develop the algorithm to provide a personalized warning on the basis of each user's level of stroke risk and a lifestyle correction message about the stroke risk factors.

Methods: Subject to national health examinees in 2002–2003, the stroke prediction model identified when stroke was first diagnosed by following-up the cohort until 2013 and estimated a 10-year probability of stroke. It sorted the user's individual probability of stroke into five categories – normal, slightly high, high, risky, very risky, according to the five ranges of average probability of stroke in comparison to total population – less than 50 percentile, 50–70, 70–90, 90–99.9, more than 99.9 percentile, and constructed the personalized warning and lifestyle correction messages by each category.

Results: Risk factors in stroke risk model include the age, BMI, cholesterol, hypertension, diabetes, smoking status and intensity, physical activity, alcohol drinking, past history (hypertension, coronary heart disease) and family history (stroke, coronary heart disease). The AUC values of stroke risk prediction model from the external validation data set were 0.83 in men and 0.82 in women, which showed a high predictive power. The probability of stroke within 10 years for men in normal group (less than 50 percentile) was less than 3.92% and those in very risky group (top 0.01 percentile) was 66.2% and over. The women's probability of stroke within 10 years was less than 3.77% in normal group (less than 50 percentile) and 55.24% and over in very risky group.

Conclusions: This study developed the stroke risk prediction model and the personalized warning and the lifestyle correction message based on the national health examination data and uploaded them to the personal health record service called *My Health Bank* in the health information website - *Health iN*. By doing so, it urged medical users to strengthen the motivation of health management and induced changes in their health behaviors.

1. Introduction

As the living standards of medical service users improve and the medical technology develops rapidly, the focus of health care is shifting to health promotion and disease prevention, rather than treatment of diseases [1]. In addition, the interest of medical service users in health is increasingly growing, and the desire to determine their own health related factors is increasing. Efforts are being made to identify their own health risks and to prevent diseases before they occur.

The National Health Insurance Service (NHIS), which has the health screening-related information of the entire nation in Korea, provides the Personalized Healthcare Program from The Personal Health Record (PHR) so called "My Health Bank" on the website

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of the health iN (http://hi.nhis.or.kr/main.do). It presents various health information is provided, using personal health screening results, inquiry questionnaires, medical treatment and medication information, together with the health screening data [2]. This program provides the prescription message in accordance with the results of the questionnaire about the lifestyle and the disease conditions based on the results of the health screening report and it aims to provide a service for predicting the risk of disease prevalence of major diseases for the public health.

The purpose of this study was to develop a model for predicting the prevalence of stroke within 10 years based on the National Health Screening Data of the entire nation in Korea, and to establish a risk classification for 10-year probability. The study also intends to diagnose health conditions and lifestyle through the national PHR, depending on where the risk for individual is placed and to predict the possible onset of stroke in the future so to utilize it for health care.

2. Methods

2.1. Calculation of 10-year stroke prediction probability

Subject to national health examinees in 2002–2003, the stroke prediction model estimated a 10-year probability of stroke by following-up the cohort until 2013 after identifying when stroke was first diagnosed. The data were obtained from NHIS in Korea. Out of 6885,789 participants aged 20 or older who had undergone the national health screening in 2002 and 2003, those who died before 2003 and those with a past history of any cancer, liver disease, heart disease, previous stroke, and respiratory disease were excluded from this study. After eliminating the outliers, the final number of study subjects was 5,715,311 persons (3,182,325 men, 2,532,986 women).

The outcome was diagnosed with a stroke for the first time between 2003 and 2013, and it was also defined as the main and sub disease code corresponding to I60 - I64 and I69 of International Classification of Disease 10th edition (ICD-10) with a history of receiving Magnetic Resonance Images or Computed Tomography. Fatal outcome was defined as the cause of death was I60 - I69.

Past and family history of hypertension, heart disease and stroke were defined when the subject answered as “Yes” to the corresponding questions in the health screening questionnaire. As for the physical activity classification, those who answered “no physical activity” was classified as the low activity group, while those who answered “having the physical activity 1 to 4 times per week” as the moderate activity group, and those who answered “having the physical activity 5 to 7 times per week” as the high activity group. The smoking was categorized into non-smoker, past smoker and current smoker. The smoking intensity was added to the category of current smoker that was classified as those less than 0.5 pack per day, 0.5 pack to less than 1 pack per day and over 1 pack per day. Alcohol drinking habits were classified into four categories such as not drinking, low-risk drinking, medium-risk drinking and high-risk drinking as per the World Health Organization (WHO)-Criteria for risk of chronic harm [3,4]. The total cholesterol was classified as less than 200 mg/dL, 200 mg/dL to 239 mg/dL, and 240 mg/dL and above [5]. The blood pressure was classified as normal group, prehypertension (120 mmHg < systolic blood pressure (SBP)<140 mmHg, 80 mmHg < diastolic blood pressure (DBP)<90 mmHg), Stage 1 hypertension (140 mmHg ≤ SBP < 160 mmHg, 90 mmHg ≤ DBP < 100 mmHg), and Stage 2 hypertension (SBP ≥ 160 mmHg, DBP ≥ 100 mmHg) [6]. In this study, obesity was classified by the WHO-Western Pacific Regional Office definition based on body mass index (BMI): underweight was a BMI of 18.5 kg/m^2 or less, stage 1 obesity was a BMI of 25 kg/m^2 or higher, stage 2 obesity was a BMI of 30 kg/m^2 or higher [7]. Diabetes was defined when a fasting blood glucose level was greater than 126 mg/dL or when the participants answered “yes” for the corresponding question in the health screening questionnaire.

Cox’s proportional hazard regression model was used for the prediction model, a similar method developed by Framingham study [8]. and The 10-year prediction probability (P) was obtained as follows: $(P)=1-S(t)\exp^{(f[x,M])}$and $f(x,M)=\beta_1(x_1-M_1)+\ldots+\beta_p(x_p-M_p)$. Here, β_1 and β_p were the regression coefficients of each risk factor, M_1 and M_p were the mean of the risk factors, and S(t) was the probability of survival from the stroke at the time of 10 years. The half of the data was used for model construction and the other for external validation. The model estimation and the internal validity test were conducted with the model construction data, and the external validity test was conducted on the validation data with the constructed model.

SAS 9.2 version was used as the statistical program and the AUC which estimated the ROC curve area was used to measure the discrimination ability. As the methods to measure the model’s goodness of fit, the Hosmer–Lemeshow type $\chi 2$ test was used, which compared by 10 quarters after aligning the survival probability of the Kaplan–Meier estimator considered as the observational survival probability and the predicted survival probability estimated by Cox’s proportional hazard model [9].

2.2. Classifying the user’s individual probability of stroke into five categories and uploading personalized warning and lifestyle correction messages for the each different category

The prediction of risk of stroke events within 10 years in the total population was classified into 5 ranges such as normal / slightly high / high / risky / very risky. Generally, when the risk prediction is less than 50% against the total population, the risk prediction range applicable to 50 to 70% was established as the range of ‘slightly high’, 70 to 90% as the range of ’high’ interval, 90 to 99.9% as the ’risky’ range and more than 99.9% as the ’very risky’ range. The personalized warning and lifestyle correction message was developed as per the risk for each range and uploaded for the access by individuals in the national PHR.

3. Results

3.1. Risk prediction probability of stroke risk

The number of outcome events after 10 years of follow-up for 5,715,311 subjects by gender was 10.07% (320,402 subjects) for men and 8.87% (320,402 subjects) for women. The finally selected risk factors by gender were consisted of such as age, past history of hypertension, past history of heart disease, past history of stroke, family history of heart disease, exercise, alcohol drinking, total cholesterol, smoking, hypertension, diabetes and body mass index for male, whereas they were consisted of such as age, past history of hypertension, past history of heart disease, past history of stroke, family history of heart disease, family history of stroke, exercise, alcohol drinking, total cholesterol, smoking, hypertension, diabetes and body mass index for female.

The results of the final model for the risk of stroke in the development data-set of 1,500,000 men and 1,200,000 women were as shown in Table 1. Among them, the strong risk factors of stroke were age (male: HR 1.1, 95% CI 1.099–1.101, female: HR 1.096, 95% CI 1.095–1.098), smoking (male: HR 1.476, 95% CI 1.447–1.505, female: HR 1.619, 95% CI 1.453–1.803), diabetes (male: HR 1.505, 95% CI 1.485–1.525, female: HR 1.461, 95% CI 1.438–1.484) and hypertension (male: HR 1.551, 95% CI 1.518–1.586, female: HR 1.424, 95% CI 1.388–1.461), respectively. In the case of lifestyle, appropriate

Table 1
Stroke risk prediction model - multivariate regression.

Variables		Men					Women				
		ß coefficient	P value	Hazzard Ratio	95% CI		ß coefficient	P value	Hazzard Ratio	95% CI	
Age-Mean$_{age}$, years		0.0951	<0.001	1.100	1.099	1.101	0.0920	<0.001	1.096	1.095	1.098
pH of HTN		0.1427	<0.001	1.153	1.136	1.171	0.2162	<0.001	1.241	1.223	1.260
pH of Heart disease		0.3265	<0.001	1.386	1.344	1.429	0.3077	<0.001	1.360	1.320	1.402
FH of Heart disease		−0.0475	0.008	0.954	0.921	0.988	−0.0590	0.007	0.943	0.903	0.984
FH of Stroke		NA					0.0675	<0.001	1.070	1.039	1.101
Physical activity	Low	reference					Reference				
	Morderate	−0.1912	<0.001	0.825	0.816	0.835	−0.1280	<0.001	0.880	0.866	0.894
	High	−0.1178	<0.001	0.889	0.875	0.903	−0.1155	<0.001	0.891	0.872	0.910
Alcohol Drinking	Not	reference					reference				
	Low-risk	−0.1465	<0.001	0.864	0.854	0.874	−0.0377	<0.001	0.963	0.945	0.981
	Medium-risk	−0.0164	0.152	0.984	0.962	1.006	0.1037	0.000	1.109	1.048	1.174
	High-risk	0.0721	<0.001	1.075	1.054	1.096	0.1121	0.052	1.119	0.999	1.253
Cholesterol (mg/dL)	< 200	reference					reference				
	200–240	−0.0752	<0.001	0.928	0.917	0.938	−0.0371	<0.001	0.964	0.951	0.976
	> = 240	0.0057	0.4880	1.006	0.990	1.022	0.0040	0.625	1.004	0.988	1.020
Smoking	None	reference					reference				
	Past	0.0376	<0.001	1.038	1.023	1.054	0.1870	<0.001	1.206	1.148	1.267
	Current, < 0.5 pack/day	0.2735	<0.001	1.315	1.293	1.336	0.3325	<0.001	1.394	1.350	1.440
	Current, 0.5–1 pack/day	0.3053	<0.001	1.357	1.338	1.376	0.4402	<0.001	1.553	1.475	1.635
	Current, > = 1 pack/day	0.3893	<0.001	1.476	1.447	1.505	0.4816	<0.001	1.619	1.453	1.803
HTN	Normal	reference					reference				
	Pre-HTN	0.0903	<0.001	1.095	1.081	1.108	0.1206	<0.001	1.128	1.113	1.144
	Stage 1	0.2375	<0.001	1.268	1.250	1.287	0.2167	<0.001	1.242	1.221	1.263
	Stage 2	0.4391	<0.001	1.551	1.518	1.586	0.3536	<0.001	1.424	1.388	1.461
Diabetes		0.4089	<0.001	1.505	1.485	1.525	0.3790	<0.001	1.461	1.438	1.484
BMI (kg/m^2)	< 18.5	0.3454	<0.001	1.413	1.379	1.447	0.2335	<0.001	1.263	1.225	1.302
	18.5–23	reference					reference				
	23–25	−0.1273	<0.001	0.880	0.869	0.892	−0.0366	<0.001	0.964	0.949	0.979
	> 25	−0.1194	<0.001	0.887	0.876	0.899	−0.0225	0.003	0.978	0.964	0.992
	> 30	0.0121	0.505	1.012	0.977	1.049	0.0416	0.005	1.042	1.013	1.073

Abbreviation:
NA: Not Available, pH: Past history, FH: Family history, HTN: Hypertension, BMI: Body Mass Index

Table 2
Discrimination and Hosmer–Lemeshow's type chi-square test for stroke risk prediction models for external validation set.

	Men	Women
AUC (area under the ROC)	0.83 (95% CI - 0.82,0.84),	0.82 (95% CI 0.81,0.83)
Hosmer and Lemeshow's type $\chi 2$	186.19 (p-value<0.0001)	111.21 (p-value<0.0001)

physical activity was analyzed to reduce the risk of stroke (male: HR 0.825, 95% CI 0.818–0.835, female: HR 0.880, 95% CI 0.866–0.894) and the high-risk alcohol drinking was analyzed to increase the risk of stroke (male: HR 1.075, 95% CI 1.054–1.096, female: HR 1.119, 95% CI 0.999–1.253) (Table 1). Based on this analysis, the stroke risk equation can be statistically calculated and the coefficients of the selected risk factors were computed. From these, a linear function of 10-year stroke prediction probability was estimated.

We estimated the AUC of the 10-year stroke prediction probability of the external validation data set in 1,682,325 men and 1,332,986 women for discrimination. It was 0.83(95% CI 0.82–0.84) for men, and 0.82 (95% CI 0.81–0.83) for women, presenting high discrimination (Table 2). Hosmer and Lemeshow's type $\chi 2$ test, which compared the Kaplan-Meier estimate with the predictive model, was not a problem as it was the value of the model fit in the large-volume data as 186.19 for male and 111.21 for female. Also, the observation probability and the prediction probability showed that there was not a big difference (Table 2).

3.2. Classifying 10-year probability of stroke and uploading lifestyle correction messages of the risk factor

The 10-year probability of stroke for men was less than 3.92% in the normal group (50%), 8.54% for 70%, and 26.53% for 90%. Then when the probability of stroke for men was more than 66.2% of the subjects, it was diagnosed as a very high risky group as more than 0.01% of the subjects. The predictive probabilities of the risk for stroke incidence for 10 years for women was less than 3.92% in the normal group (50%), 8.46% for 70%, and 8.46% for 90%. Then when the risk of stroke incidence for women was more than 55.24% of the subjects, it was diagnosed as a very high risky group as more than 0.01% of the subjects (Table 3).

Table 3
Classification of 10-year probability of stroke.

Probability	Male	Female
50%	0.039160	0.037653
70%	0.085476	0.084591
90%	0.265250	0.228440
99.9%	0.661600	0.552380

The probability of stroke was calculated using the model equation by automatically reading the health screening data of the users. In addition, if there is no information on the health screening in the NHIS, the risk probability cannot be calculated automatically. Therefore, the self-entry was enabled to fill in the web page. A comparison was performed with the mean risk of stroke in the same age group and the difference of each risk factor was displayed and provided to the users of the web page (Fig. 1).

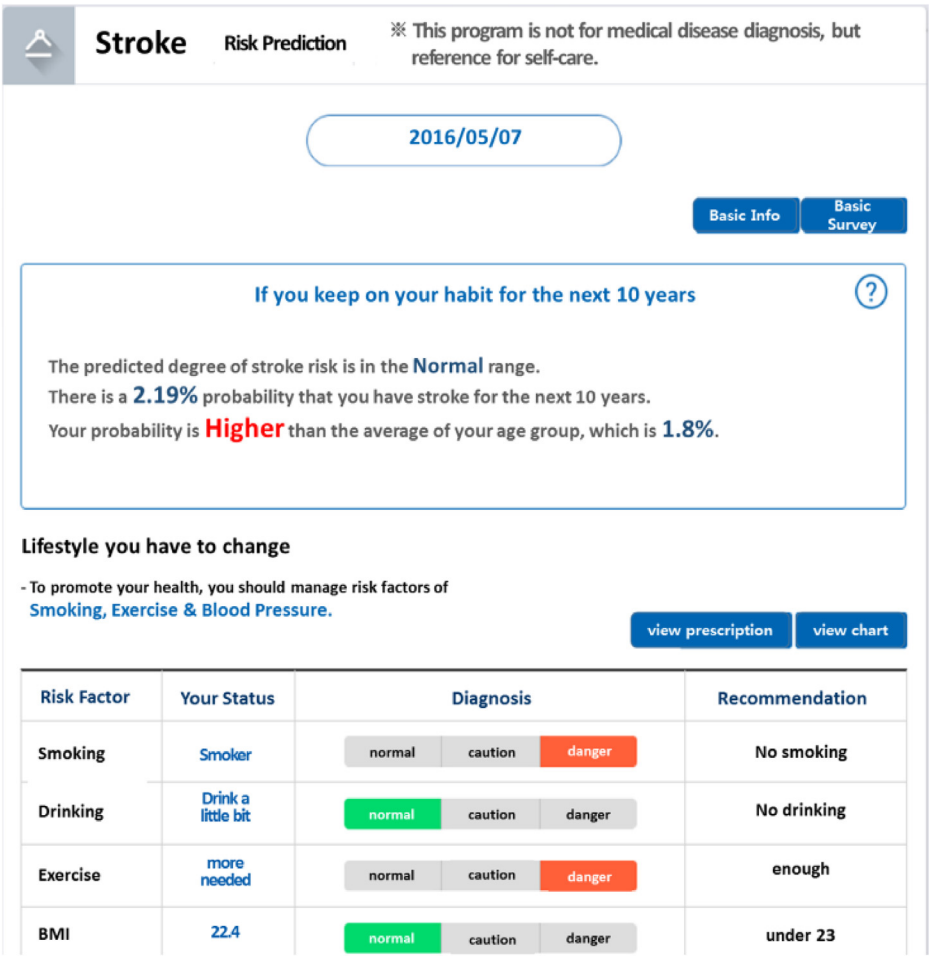

Fig. 1. Stroke risk prediction program in *Health-iN* web site.

The risk factors such as exercise, drinking, smoking, cholesterol, blood pressure, BMI, and glucose were categorized into normal / caution / danger zone. As per the lifestyle habits in need of improvement, the range was developed to be displayed with different colors just like the health light signals. A lifestyle correction message by each risk factor was developed and set to automatically pop up in the individual PHR.

4. Discussion

Although there are several studies in different countries on predicting the risk of stroke [8,10–12], this study is significant in terms that it had used the data from the national health examination of the entire nation and investigated the onset of stroke incidence in 10 years after as a cohort study. A comparison of the differences in the magnitude of the risk factors by each item in the Korean population with the differences in that of the risk factors in the study of other countries can be performed later.

Although the risk for each range was divided into five groups, in the case of a 10-year prediction probability of stroke, the incidence rate equivalent to 50% of the subjects was 3.92% for male and 3.77% for female, and the upper 0.01% of the risk rate was 66.2% for male and 55.24% for female. It indicated that the risk within the same range should be categorized into a common message, so as in the future a method is needed to express even the detailed risks of individual by categorization.

This study is meaningful as a 10-year follow-up study using national health screening big dataset for the entire Korean population. But, there are the following limitations. First, we could not include all of the risk factors such as atrial fibrillation (AF). AF patients have a 5-fold increase in stroke risk and the risk further increases with age [13,14]. And it is well known that the risk of hemorrhagic stroke is increased with the presence of cerebral aneurysm. However, we could not obtain the data for the risk factors such as atrial fibrillation and cerebral aneurysm. The research data used in this paper is composed of the total national health examination data in Korea and the medical claim data of the patient. The national health screening program in Korea does not include high cost examination such as atrial fibrillation and there is no atrial fibrillation result in the claim data. In the subsequent studies, we might need a more predictive study design, including such medical records, increasing risk of stroke. Second, this study did not distinguish ischemic and hemorrhagic strokes in the diagnosis of stroke. Atrial fibrillation is associated with an increased risk of ischemic stroke, and aspirin is known to be associated with a higher risk of hemorrhagic stroke [15]. And previous studies [16] have shown that the risk of death from ischemic stroke is increased by 25%, but hemorrhagic stroke is reduced by 20% when total cholesterol is increased by 1 mmol/L in Asia. But, as the purpose of this study was to prevent stroke event in order to promote public health, the data was collected without differentiation between ischemic and hemorrhagic stroke at first. Also, the doctors tend not to distinguish type of stroke well when they enter the diagnostic code (ICD-10) of stroke in Korea. In a previous study [17] that reported the diagnostic accuracy of ICD-10 for stroke in Korea, only 68 out of 174 cases of I60–62 (hemorrhagic stroke)

were actually hemorrhagic stroke and 56 were ischemic stroke. Among 289 cases with I63 (ischemic stroke), only 131 cases were actually ischemic stroke and 67 cases were hemorrhagic stroke. However, when the stroke was defined as a combination of ischemic or hemorrhagic stroke codes, the diagnostic accuracy was reported to be 83.4%. As such, there is a limitation in accurately distinguishing types of stroke in Korea because the diagnostic code of the medical insurance claim data may be inaccurate. A previous study [12] reporting the first stroke prediction model in Korea was used as an outcome that included both ischemic and hemorrhagic strokes and reported that the AUC was more than 80%. Although these limitations exist, it is necessary to differentiate and predict the stroke separately, so a more sophisticated model is needed by constructing accurate data sets with separate hemorrhagic and ischemic stroke. Lastly, more sophisticated analyses such as NRI (Net reclassification index) and IDI (Integrated discrimination index) are required in the methods of model analysis.

Nevertheless, even if there are such limitations, this study, using the National Health Examination Data of entire population in Korea is meaningful because we established a risk classification for 10-year probability of stroke according to 10-year follow-up and made personalized message to be implemented in real-time web.

Although many web programs have been developed for changes in public lifestyles [6,18–24], it has not been able to provide PHR health promotion services to the public by using the nationwide big data of the country. This study had obtained the predictive probability for the risk of stroke through analyzing all the respective health risk factors such as lifestyle, family history, and test results of all people based on the national health screening data provided to all people in Korea. Through such analyses, it developed a disease prediction program, and uploaded the program to PHR web page of the National Health Insurance Service. As the study analyzed the health conditions and the lifestyles and provided the services to predict future diseases, depending on the risk of individual, it had contributed to providing effective medical care services of the National Health Screening and at the same time to improving of the user compliance.

5. Conclusion

This study developed a model for predicting the prevalence of stroke within 10 years based on the National Health Screening Data of the entire nation in Korea and established a risk classification for 10-year probability. And also developed the personalized warning and the lifestyle correction message about the stroke risk factors and uploaded them to the Personal Health Record service called My Health Bank in the health information website - Health iN). By doing so, it urged medical users to strengthen the motivation of health management and induced changes in their health behaviors.

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Conflict of interest

The authors herein declare no conflicts of interest that could prevent the publication of this article.

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