Paper No: SC-01 **Smart Computing**

Towards detecting morning surge from sleep self-evaluations

Masakazu Takahashi*
Graduate School of Innovation and Technology Management
Yamaguchi University, Japan
masakazu@yamaguchi-u.ac.jp

Noriyuki Sugahara
Graduate School of Sciences and Technology for Innovation
Yamaguchi University, Japan
b003wc@yamaguchi-u.ac.jp

Masashi Shibata
Graduate School of Sciences and Technology for Innovation
Yamaguchi University, Japan
g501wc@yamaguchi-u.ac.jp

***Abstract*: This paper aims to analyze the blood pressure transition during sleep. Morning surge is a sudden increase in blood pressure from awakening or before awakening. Morning surge is implicated in cardiovascular diseases, such as Stroke, Angina Pectoris, and Myocardial Infarction. Morning surge has been detected mainly by the ABPM (Ambulatory Blood Pressure Monitoring) method, which measures blood pressure for 24-hours. Since the ABPM method cannot distinguish awakening and sleep automatically, their alternative method is forcibly delimiting time or manually processing based on behaviour records. Therefore, it is necessary to capture the blood pressure change under clear sleep separation. This paper employs two sleep criteria for accurate blood pressure during sleep.**

Keywords: *Blood pressure, Clustering, Hypertension, Machine learning, Unsupervised learning*

I. INTRODUCTION

Blood pressure indicates the pressure that blood applies to blood vessels. The heart contracts in sending blood. The pressure applied to the blood vessel at this contract time is called the SBP (Systolic Blood Pressure). SBP shows the highest value in mmHg. On the contrary, when the blood returns to the heart, the heart expands. The blood pressure at this time is called DBP (Diastolic Blood Pressure) with the lowest score.

Hypertension exhibits excessive state in which the pressure is exerted on the vessel. The continuation of hypertension imposes a burden on blood vessels, and the risk of cerebral hemorrhage occurring due to the rupture of blood vessels in the brain is increased. Further, the heart gradually increases as it attempts to submit blood flow, cardiac hypertrophy. As the cardiac hypertrophy progresses, the movement of the heart strikes and the function of delivering blood to the whole-body decreases. Thus, hypertension causes various diseases.

When the early morning blood pressure rises sharply before or after waking up early in the morning, it is called Morning surge. Morning surge is thought to be involved in the pathology of cardiovascular disease independent of normal blood pressure fluctuations.

Morning surge has been detected mainly by the ABPM (Ambulatory Blood Pressure Monitoring) method. The ABPM measures blood pressure for 24 hours every 15 minutes. However, both hypertension standards and normotensive pressure standards by the ABPM are not specified. Furthermore, there is no unique method for efficiently separating daytime and nighttime. The separation between daytime and nighttime in the ABPM is made by the fixed time and merged from the record of patients' behaviour.

In this paper, data analysis is made for morning surge detection by capturing the distinction between sleeping and awakening. The rest of the paper is organized as follows. Section 2 discusses the backgrounds of the research and related work; Section 3 briefly summarizes the gathered data from the target clinics; Section 4 describes the analytics of the data and presents analytical results; and Section 5 gives concluding remarks and future work.

II. RELATED WORK

The Ministry of Health, Labor and Welfare, Japan defines hypertension as a disease that increases blood pressure and increases the risk of stroke or heart disease [1]. It is estimated that the number of Japanese patients with hypertension is approximately 43 million. As blood pressure rises, it gradually inflicts damage to the brain and heart. Therefore, if we ignore a high blood pressure conditions, the probability of causing a stroke or myocardial infarction and causing sudden death increases. It is estimated that as the SBP rises by ten mmHg, the risk of stroke increases by about 20% and the risk of angina and myocardial infarction by about 15% [2]. Therefore, the blood pressure value is one of the essential indicators that can evaluate the risk of stroke onset or myocardial infarction.

Hypertension Treatment Guidelines 2014 was the world's first, which stated that in case of a blood pressure gap between the examination room and home, home blood pressure should be given priority in hypertension diagnosis. Further, it defines reference values of the blood pressure by the measurement conditions as follows:

In hospital: more than 140 mmHg in SBP or more than 90 mmHg in DBP

In-home: more than 135 mmHg in SBP or more than 85 mmHg in DBP

Hypertension is divided into essential hypertension and secondary hypertension categories. Approximately 85% to 90% is an essential one, and causes of blood pressure increase cannot be identified due to multiple causes such as genetic predisposition, lifestyle, weight, stress, and other factors. The rest is identified as secondary hypertension, which is caused by certain diseases. Secondary hypertension can be identified, and healing and improvement can be expected by appropriate diagnosis and treatment [3].

Blood pressure changes during sleep also increases when the sympathetic is actively working due to stress. Hypertension is followed by hardness and fragility in arteries and becomes arteriosclerosis. Moreover, hypertension causes various diseases in the brain and heart. The report says that the higher the blood pressure, the higher the risk of death from cerebral cardiovascular diseases such as stroke and myocardial infarction [4]. Conventionally, diagnosis and treatment of hypertension have been carried out based on occasional blood pressure in the outpatient examination. In 2009, the JAMP (Japan Ambulatory Blood Pressure Prospective Study) was launched [5]. It was an epidemiological study that measures blood pressure for 24 hours using the ABPM Study (Ambulatory Blood Pressure Monitoring). From this study, the importance of blood pressure fluctuation during sleep was found. Furthermore, blood pressure fluctuation was classified as follows [6].

Coat hypertension: Elevation of blood pressure only at the outpatient examination.

Morning surge: Early-morning boost in which blood pressure rises sharply in early morning awakening or before arousal.

Non-dipper: Does not show nocturnal depression observed in normotensive subjects.

Following findings are made such as the blood pressure fluctuation, the morning surge of elderly hypertension becomes a stroke risk independently of the 24-hour blood pressure level and morning surge has become a cardiovascular event risk [7] - [12].

One of the features of the ABPM method is a number of measurements [13]. The average blood pressure values with many numbers of measurements well reflect the patient's blood pressure condition [14]. The ABPM with many blood pressure measurements can predict cardiovascular organ disorders, and the prognosis of patients was reported [15].

The sixth report of the Joint Committee of the United States in 1997 (JNC-VI) and the WHO / ISH hypertension guidelines in 1999 has presented the normal range of ABPM [16] [17].

The reference values are also presented for blood pressure at daytime and at the sleeping time [18]. However, the criteria for hypertension and normotensive pressure are not specified. Furthermore, there is no unified separation method for separating daytime and nighttime so far. Currently, it is processed by the integration with the methods and activity record delimiting the time to wake-up and sleep at a fixed time.

J-MUBA (Japanese Multicenter Study on Barnidipine with the ABPM), was to evaluate the antihypertensive effect of barnidipine by 24-hour blood pressure measurement (ABPM) using a portable automatic sphygmomanometer. They separate the daytime and sleeping from the activity records manually. As a result, there is almost no difference between the two methods, and these two methods are applied for day and night separation [19].

In the ABPM method, measurement is frequently performed in the daytime and low frequency in the night. Therefore, in order to calculate the average value of the 24-hour blood pressure, the correction of Equation (1) is required.

24-hour ABPM average = (Daytime blood pressure average) x (Arousal hour) + (Nighttime blood pressure average) x (Sleeping time) / 24 (1)

The definition of early morning hypertension is divided into broad and narrow interpretation shown by Equation (2) to Equation (6) [20].

Broad interpretation:

$$\text{Morning Hypertension} \stackrel{\text{def}}{=} [85,135] \quad (2)$$

Narrow interpretation:

Definition 1

$$\text{Morning Blood Pressure} \stackrel{\text{def}}{=} [85,135] \quad (3)$$

$$\text{Bedtime Blood Pressure} \stackrel{\text{def}}{=}]85,135[\quad (4)$$

Definition 2

$$\text{ME Average} \stackrel{\text{def}}{=} [85,135] \quad (5)$$

$$\text{ME Difference} \stackrel{\text{def}}{=}]85,135[\quad (6)$$

Where ME Average and ME Difference are expressed by Equation (7) and Equation (8).

ME Average = (Morning Blood Pressure + Bedtime Blood Pressure)/2 (7)

ME Difference = (Morning Blood Pressure – Bedtime Blood Pressure) (8)

Accordingly, classification based on blood pressure is shown in Fig. 1, and the morning surge group is also indicated by Equation (9) to Equation (12) [7].

Morning surge group:

Daytime surge (in SBP) $\geqq$ 45-55 mmHg (9)

Morning blood pressure = (Average blood pressure for two-hours after waking up) (10)

Nighttime lowest blood pressure = (Average two-hour blood pressure including nighttime lowest pressure) (11)

Daytime surge = (Morning blood pressure) – (Nighttime lowest blood pressure) (12)

Prehypertension clusters are defined as Masked Hypertension, where both clinical blood pressure and blood pressure average are not high, but midnight surge comes from sleep apnea syndrome and morning high blood pressure [21]. Therefore, capturing accurate blood pressure fluctuation makes it possible to predict the vascular risk of the brain, heart, kidney, and other organs. The primary issue of blood pressure measurement at night, such as the ABPM is clear identification of sleeping and awakening.

In this paper, the analytical results based on the nighttime blood pressure measurement using equipment allow each person to operate and measure the wake-up time clearly before sleeping and awakening is described. Furthermore, the two types of sleep level surveys are merged with this result.

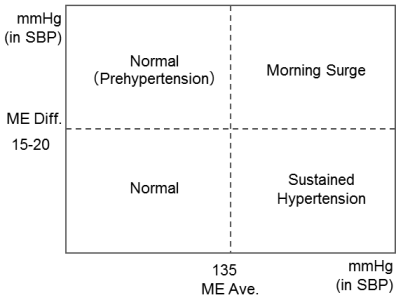

Fig. 1. Hypertension classification by average and difference score in SBP

III. Experimental Configuration

For the measurement method of nocturnal blood pressure, a blood pressure monitor is lent to a patient diagnosed as hypertension, and blood pressure is monitored for a week. Fig.2 shows the examination and blood pressure data collection cycle.

With the Sphygmomanometer, blood pressures before sleeping and immediately after waking up are measured at regular intervals by button operation before going to bed and after waking up. In this trial, it was made every hour at night. Table I indicates the result of gathering data.

In the ordinal hypertension examination, physicians focus on the value of SBP. Therefore, Table II shows the patients' experimental summary in SBP. Since the living cycle differs from each patient to patient, the nighttime blood pressure was taken from 2 o'clock to 5 o'clock in the nighttime analysis.

As for the insomnia determination method, the PQSI (Pittsburgh Sleep Quality Index) and the AIS (Athens Insomnia Scale) are popular [22] [23]. These are intended to determine the sleep quality from the questionnaire.

The PSQI is a self-written questionnaire development to evaluate sleep and its quality. The AIS is a worldwide standard insomnia assessment method created by WHO (the World Health Organization) with the World Project on Sleep and Health project.

The answers to the subjective sleep level of the patient were merged in addition to the objective sleep level in AIS to investigate the relationship between the blood pressure transition and the sleep level during the night.

The sleep level scale of HNC was evaluated in 7 scales. This scale was made after collecting the blood pressure record for one week, and the scale is from 1 as “well slept” to 7 as “insomnia”.

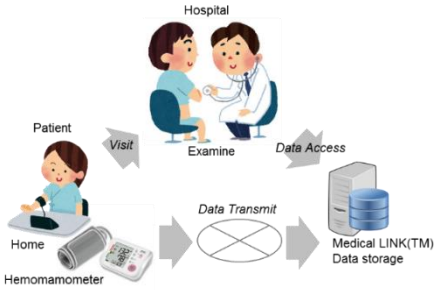

Fig. 2. Examination flow

TABLE I. Gathering Data Attributes

Term	2015/11/1-2017/07/01
Number of Clients	140 clients
Number of Records	20,102 (104 records were excluded for machine error)
Record Information	ID, Date, Hour, SBP, DBP, Pulse, Temperature, Time Flag, ASL Sleep Level, Original Sleep Level
Hemomamometer	HEM-8723A-ND

TABLE II. Experimental Summary in SBP

Hour	**N**	**Ave.**	**Med.**	**S.D.**	**Min.**	**Max.**
E	5,208	121	120	16	73	216
23	7	90	90	9	78	101
0	19	103	107	10	88	116
1	275	112	113	15	65	151
2	2,460	114	113	16	65	202
3	2,440	114	112	15	62	179
4	2,362	114	113	15	71	188
5	2,004	116	114	15	68	187
6	73	115	113	17	81	170
Total	19,998	119	118	16	62	216

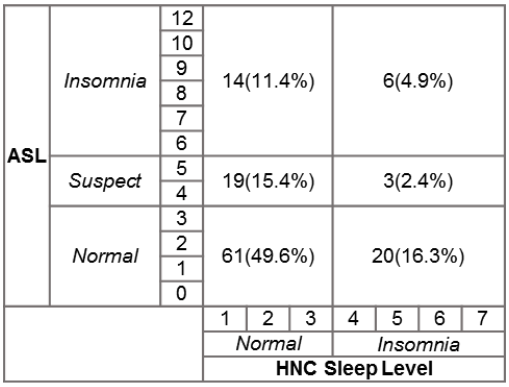

Fig. 3. Sleep relation between ASL and HNC

The sleeping level was set as the NHC sleep level. Both the ASL and the HNC are defined by the following Equation (13) and Equation (14).

$$\mathrm{NHC} \stackrel{\text{def}}{=} [1, 7] \tag{13}$$

$$\mathrm{ASL} \stackrel{\text{def}}{=} [0, 10] \tag{14}$$

The number of patients satisfying Equation (15) amount to 123 patients.

$$\text{HNC} \cap \text{ASL} \tag{15}$$

In the ASL scale, scales 4 and 5 are suspected of insomnia. In the HNC, Scale 4-7 is insomnia suspect. Fig. 3 shows the relationship between two sleeping levels. 49.6% of the patients had proper sleep levels for both the ASL and the HNC. 4.9% of patients who both became insomnia in both indices are also partly stressful against nighttime measurement.

As a result, there is no better sleep during the trial.

IV. Experimental Result

Table III indicates the experimental summary in SBP from night to morning. Then, potential moring surge patients were extracted. Based on Equation (7) and Equation (8), two patients could be identified as morning surge patients, whose sleep levels are indicated in Table. IV. These patients responded that they were sleeping well by self-assessment, but there is doubt of insomnia.

Fig. 4 and Fig. 5 are indicated time-series transition of blood pressure.

In Fig. 4, This patient was scored 0 in ASL, and the score of Equation (9) was 61. In Fig. 5, This patient was scored 4 in ASL, and the score of Equation (9) was 47.

Thus, by integrating multiple sleeping levels and observation of night blood pressure, it is possible to discover patients with a possibility of morning surge.

Then, clustering was performed only with the transition of nocturnal blood pressure separately from multiple sleep indices. Clustering is a dividing method of a set of classification objects into subsets such that internal cohesion and external isolation are achieved [24].

The clustering method can be classified into a hierarchical method such as the shortest distance method and a non - hierarchical method such as the k-means method. This time, the Ward's method was selected.

This paper, the 103 patients with a score of 19 or higher who replied to the ASL and the HNC were subjected to clustering based on the average of the period.

Both Table V. and Fig. 6. show the SBP blood pressure transition of five clusters.

TABLE III. Experimental Summary in SBP

Hour	**E**	**2**	**3**	**4**	**5**	**M**
Ave.	119	110	110	110	112	126
S.D.	20	19	19	19	18	19
Min.	79	65	74	71	76	92
Max.	168	148	179	161	161	174
Med.	118	110	110	110	112	125
Mod.	121	110	111	111	112	118
N	1,254	564	564	546	423	1,258

TABLE IV. Experimental Summary in SBP and Sleep levels

Id	**E**	**M**	**ME Ave.**	**ME Diff.**	**NHC**	**ASL**	**Eq. (9) Score**
(a)	117	160	138	44	1	0	61
(b)	126	135	130	9	1	4	47

TABLE V. Average SBP by cluster

Cluster	**E**	**S2**	**S3**	**S4**	**S5**	**M**	**N**
1	125	112	111	109	111	133	**17**
2	115	111	111	111	112	119	**31**
3	111	97	99	99	103	118	**17**
4	131	119	118	121	121	137	**23**
5	126	129	132	130	128	128	**15**

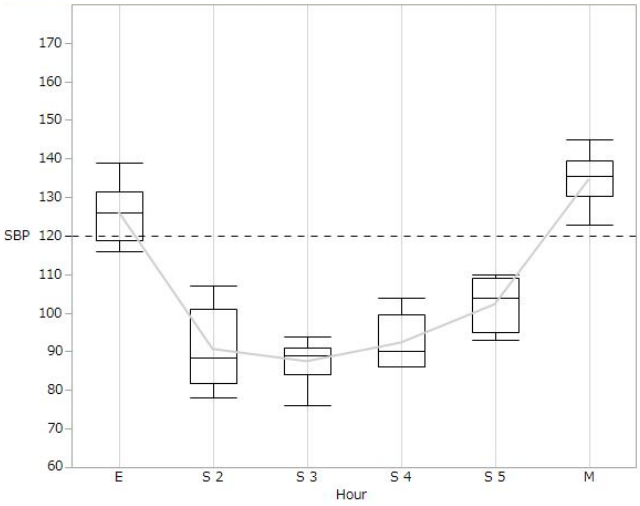

Fig. 4. SBP transition (a)

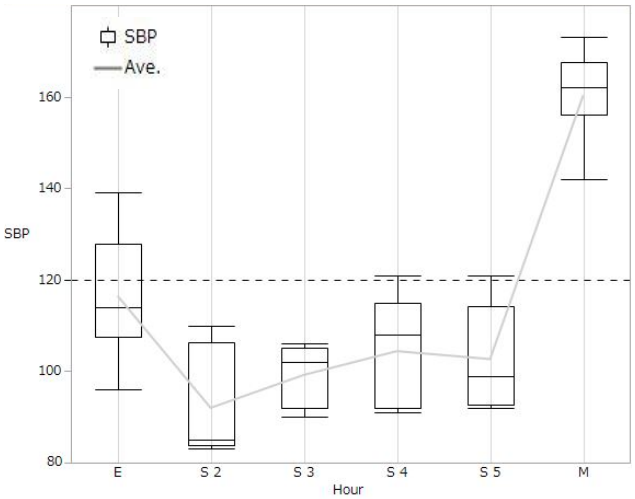

Fig. 5. SBP transition (b)

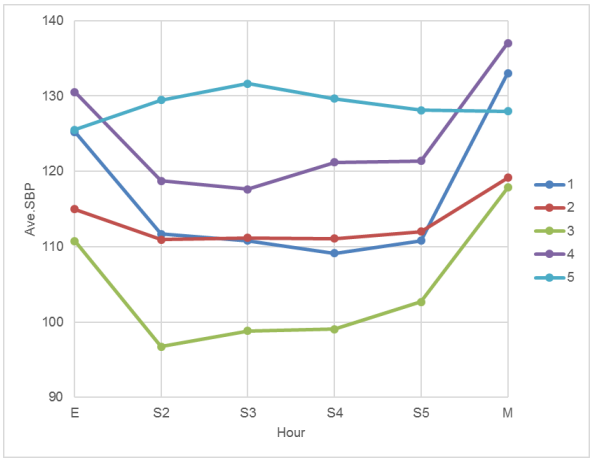

Fig. 6. SBP transitions by cluster

Cluster 1 can be thought of as a morning surge that blood pressure rises early in the morning. and Cluster 5, since their blood pressure did not fall below 120mmHg even once the middle of the night, it can be considered that they could not sleep at that time.

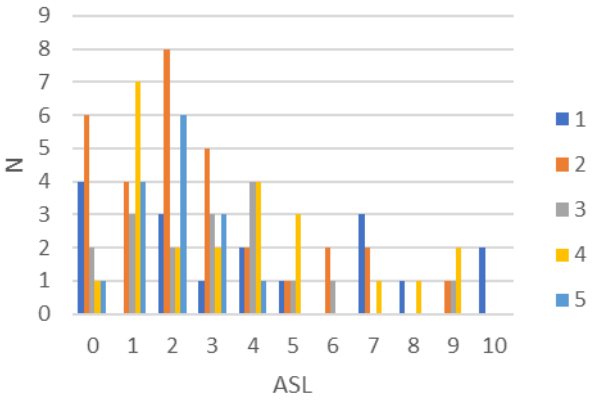

Fig. 7. ASL score by the cluster

Fig. 6 shows the ASL score of each cluster. Among those who were classified into cluster 1, there were patients elevated blood pressure in the early morning even though they were able to sleep from the objective evaluation with the low-scored ASL.

Then, the Distribution of ASL scores for each cluster is considered. Fig. 7 indicates the ASL score distribution for each cluster. In cluster 1, there were 4 patients with an ASL score of 0, No patient with ASL score of 1 and 3 patients with ASL score of 2. When the relationship of the transition of SBP and the ASL score is considered, unconscious insomnia based morning surge is able to be detected.

V. Concluding Remarks

This paper presented investigating for analyzing blood pressure transition from the clinical records, which aims to classify the patients' blood pressure surge type.

We described research backgrounds, related wok, research method, proposed a method and analytical results.

Concerning the screening of suspicious blood pressure surge patients, it depends on the heuristic knowledge of cardiology doctors, not only the observation of blood pressure. Since to predict the accurate diagnosis of hypertension, both the subjective and objective sleep level was focused not only on the transition of the blood pressure. The analytical results suggested that potential hypertension clusters were extracted. As a result, it is possible to classify the transition patterns. This finding will assist in practical cardiology therapy.

Our future work includes; 1) parameter tuning for the accurate classification, 2) examine another machine learning method such as an xgboost, 3) generate new transition patterns with meta-heuristic algorithms. This work will require practical experiments and further survey studies.

References

[1] K. Shimamoto et al., "The Japanese Society of Hypertension Guidelines for the Management of Hypertension (JSH 2014)," Hypertens. Res., vol. 37, no. 4, 2014, pp. 253–253.

[2] Ministry of Health, "A Basic Direction for Comprehensive Implementation of National Health Promotion," 2012 [Online]. Available:http://www.mhlw.go.jp/seisakunitsuite/bunya/kenkou_iryou/kenkou/kenkounippon21/en/kenkounippon21/index.html. [Accessed: 08/01/2020].

[3] K.Yatsu, T.Umemura "Management of Secondary Hypertension.," Heart View, 2015, pp.350-354.

[4] A. Fujiyoshi et al., "Blood pressure categories and long-term risk of cardiovascular disease according to age group in Japanese men and women," Hypertens. Res., vol. 35, no. 9, 2012, pp. 947–953.

[5] "Japan Ambulatory Blood Pressure Prospective Study: JAMP study," UMIN-CTR Clinical Trial. [Online]. Available: https://upload.umin.ac.jp/cgi-openbin/ctr_e/ctr_view.cgi?recptno=R000023397. [Accessed: 05-03-2020]

[6] K. Kario, "Time for focus on morning hypertension: Pitfall of current antihypertensive medication," American Journal of Hypertension, vol. 18, no. 2. 2005, pp. 149–151.

[7] K. Kario et al., "Morning surge in blood pressure as a predictor of silent and clinical cerebrovascular disease in elderly hypertensives: A prospective study," Circulation, vol. 107, no. 10, 2003, pp. 1401–1406.

[8] P. Gosse, R. Lasserre, C. Minifié, P. Lemetayer and J. Clementy, "Blood pressure surge on rising," J. Hypertens., vol. 22, no. 6, pp. 1113–1118, Jun. 2004, doi: 10.1097/00004872-200406000-00011.

[9] H. Metoki et al., "Prognostic significance for stroke of a morning pressor surge and a nocturnal blood pressure decline: The Ohasama study," Hypertension, vol. 47, no. 2, 2006, pp. 149–154. doi: 10.1161/01.HYP.0000198541.12640.0f.

[10]"JALS -Japan Arteriosclerosis Longitudinal Study." [Online]. Available: http://jals.gr.jp/en/index.html. [Accessed: 05-03-2020]

[11] A. Amici et al., "Exaggerated morning blood pressure surge and cardiovascular events. A 5-year longitudinal study in normotensive and well-controlled hypertensive elderly," Arch. Gerontol. Geriatr., vol. 49, no. 2, 2009, pp. e105–e109. doi: 10.1016/j.archger.2008.10.003.

[12] Y. Li et al., "Prognostic value of the morning blood pressure surge in 5645 subjects from 8 populations," Hypertension, vol. 55, no. 4, 2010, pp. 1040–1048. doi: 10.1161/HYPERTENSIONAHA.109.137273.

[13] J.-M. Mallion, J.-P. Baguet, J.-P. Siché, F. Tremel, and R. De Gaudemaris, "Clinical value of ambulatory blood pressure monitoring," J. Hypertens., vol. 17, no. 5, 1999, pp. 585–595. doi: 10.1097/00004872-199917050-00001.

[14] S. Trazzi, E. Mutti, A. Frattola, B. Imholz, G. Parati, and G. Mancia, "Reproducibility of non-invasive and intra-arterial blood pressure monitoring: Implications for studies on antihypertensive treatment," J. Hypertens., vol. 9, no. 2, 1991, pp. 115–119. doi: 10.1097/00004872-199102000-00003.

[15] Y. Imai, "Prognostic significance of ambulatory blood pressure.," Blood Press. Monit., vol. 4, no. 5, 1999, pp. 249–256. doi: 10.1097/00126097-199900450-00007.

[16] E. J. Roccella, "The Sixth Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure," Archives of Internal Medicine, vol. 157, no. 21.,1997, pp. 2413–2446.

[17] WHO-ISH, "1999 World Health Organization-International Society of Hypertension Guidelines for the Management of Hypertension. Guidelines Subcommittee," J Hypertens, vol. 17, no. 2, 1999, pp. 151–183. doi: 10.1097/00004872-199917020-00001.

[18] JCS Joint Working Group, "Guidelines for the clinical use of 24 hour ambulatory blood pressure monitoring (ABPM) (JCS 2010)-Digest version," Circulation Journal, vol. 76, no. 2, 2012, pp. 508–519.

[19] I.Kuwashima, "Japanese Multicenter Study on Barnidipine with ABPM," Japan Medical Journal, 3973, G1-G6, 2000.

[20] K.Kario "Clinician's Manual on Early Morning Risk Management in Hypertension," Science Press, 2004, pp.1-68.

[21] K. Kario, "Preceding linkage between a morning surge in blood pressure and small artery remodeling: An indicator of prehypertension?," J. Hypertens., vol. 25, no. 8, 2007, pp. 1573–1575. doi: 10.1097/HJH.0b013e32825fea8a

[22] D. J. Buysse, C. F. Reynolds, T. H. Monk, S. R. Berman, and D. J. Kupfer, "The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research," Psychiatry Res., vol. 28, no. 2, 1989, pp. 193–213, doi: 10.1016/0165-1781(89)90047-4.

[23] C. R. Soldatos, D. G. Dikeos, and T. J. Paparrigopoulos, "Athens Insomnia Scale: Validation of an instrument based on ICD-10 criteria," J. Psychosom. Res., vol. 48, no. 6, 2000, pp. 555–560. doi: 10.1016/S0022-3999(00)00095-7.

[24] S. Everitt Brian, Cluster analysis. John Wiley & Sons, 2011.