Variation in blood pressure and heart rate of radiological technologists in worktime tracked by a wearable device: A preliminary study

Ryogo Minamimoto*, Yui Yamada, Yasuharu Sugawara, Megumi Fujii, Kazuki Kotabe, Kakeru Iso, Hiroki Yokoyama, Keiichi Kurihara, Tsubasa Iwasaki, Daisuke Horikawa, Kaori Saito, Hironori Kajiwara, Futoshi Matsunaga

Department of Radiology, Department of Radiology, National Center for Global Health and Medicine, Tokyo, Japan

* ryogominamimoto@yahoo.co.jp

Abstract

The aim of this preliminary study was to measure the systolic BP (SBP) and diastolic BP (DBP) and heart rate (HR) of radiological technologists by WD, and evaluate variation among individuals by worktime, day of the week, job, and workplace. Measurements were obtained using a wristwatch-type WD with optical measurement technology that can measure SBP and DBP every 10 minutes and HR every 30 minutes. SBP, DBP, and HR data obtained at baseline and during work time were combined with the hours of work, day of the week, job, and workplace recorded by the participants in 8 consecutive weeks. We calculated the mean, the ratio to baseline and coefficient of variation [CV(%)] for SBP, DBP, and HR. SBP, DBP, and HR values were significantly higher during work hours than at baseline (p<0.03). The ratio to baseline values ranged from 1.02 to 1.26 for SBP and from 1.07 to 1.30 for DBP. The ratio to baseline for SBP and DBP showed CV(%) of approximately 10% according to the day of the week and over the study period. For HR, ratio to baseline ranged from 0.95 to 1.29. The ratio of mean BP to baseline was >1.2 at the time of starting work, middle and after lunch, and at 14:00. The ratio to baseline of SBP were 1.2 or more for irradiation, equipment accuracy control, registration of patient data, dose verification and conference time, and were also working in CT examination room, treatment planning room, linac room, and the office. CV(%) of BP and HR were generally stable for all workplaces. WD measurements of SBP, DBP, and HR were higher during working hours than at baseline and varied by the individuals, work time, job, and workplace. This method may enable evaluation of unconscious workload in individuals.

Introduction

Hypertension is a major risk factor for death and future disability [1]. Reduced heart rate (HR) variability can be caused by poor autonomic nervous system adaptability, and it is associated with fatigue, stress, and overtraining that can be an early indication of illness and infection [2–
Although hypertension is rare in young people, most are aware of their normal blood pressure (BP) values, which are monitored at health checks performed once or twice annually or by self-monitoring at home. Traditional clinical research aiming at monitoring of patients has also evaluated BP at a single time point or longitudinally at select time points. BP and HR are generally measured in the sitting position and at rest, which is a different situation to when working during the day, which takes up at least one third of the day. Therefore, insufficient data have been captured to enable evaluation of the influence of variation in BP and HR during working hours on workers’ health.

Wearable device (WD) technologies can track large amounts of real-time activity and physiological data and convert it to digital data. Several clinical studies have shown that WD data can be collected effectively at scale [5–7]. A comparison of wrist-type and arm-type BP monitoring found fair agreement between the two methods for the ambulatory condition [8].

Several studies have investigated the usefulness of WD for monitoring BP and HR in patients [9–11]. Environmental factors, physical activity, and psychological stress all influence BP and HR. With the aim of increasing patient safety in the operating room, WD has also been applied to continuous BP monitoring to detect sudden changes in BP [12]. Although the accuracy of WD for HR during physical activity was presented in some studies, there has not been enough information on the accuracy it for BP.

There is a known positive association between high levels of stress at work and elevated systolic BP (SBP), and to a lesser extent with diastolic BP (DBP) [13–20]. We hypothesized that variation in BP and HR while at work could be an indicator of overwork and stressful work circumstances, and that such data could be used to improve the working environment and thus maintain the health of workers. It is uncertain whether overwork and work-related stress occur in young radiological technologists, who perform various types of work, including scanning, radiotherapy, equipment checks, and patient care. In this preliminary study, we measured SBP, DBP, and HR by WD for 8 consecutive weeks in young radiological technologists, and evaluated variation in these values between individuals and according to hour of work, day of the week, job, and workplace.

Materials and methods

Participants

This prospective study was approved by the National Center for Global Health and Medicine institutional review board (Approved number: NCGM-G-004050-00), and written informed consent was obtained from all participants prior to the study. Included in the study were seven radiological technologists working at our hospital (six men, one woman; mean age (±SD), 29.6 ±4.0 years; age range, 22–35 years). Mean duration of total work experience was 7.2±3.1 years and mean duration of work experience in the division was 3.6±3.6 years. Four of the seven technologists worked in the division of radiation therapy (mean experience in that division, 8.5 years) and the remaining three worked in the division of nuclear medicine (mean experience in that division, 5.5 years). No participant had any history of illness or was taking medication during the study period. Participants’ work descriptions and work locations are listed in Table 1.

Measurement of BP and HR

SBP, DBP, and HR were measured using a wristwatch-type WD (itDEAL Smart Watch W11; itDEAL, China). The device can measure SBP and DBP every 10 minutes and HR every 30 minutes using optical measurement technology.

To stabilize the measurements, participants wore the device on the left wrist for approximately one week during work time. After this period, all participants attended an interview in...
which they were asked about their medical history and medications, as well as their job, workplace (division), and their years of experience overall and in that division. Participants selected their job and workplace from a list, and recorded these details using a provided Excel spreadsheet for each daily measurement period.

With the participant seated and with both arms resting on the table at a similar level to the heart, we recorded SBP, DBP, and HR three times at the right upper arm of each participant using a conventional oscillometric-type sphygmomanometer and pulse monitor measurement device approved in Japan for clinical use (UA-772B; A&D Co. Ltd., Tokyo, Japan). Baseline WD measurements of SBP, DBP, and HR were recorded simultaneously three times at the left wrist, at 17:00. Measurements of SBP, DBP, and HR were then begun on workdays between 7:00 and 18:00, and were recorded during any consecutive 8-week period between May and October 2021.

### Data migration

Measurement data from the WDs were sent to smartphones (Geanee ADP-503G; JENESIS Co. Ltd., Tokyo, Japan) onto which the H Band 2.0 recording application was downloaded. Each WD was linked to an individual smartphone via Bluetooth. The smartphones were used only to obtain data from WD. They had no call function and were restricted from connecting to any network except Bluetooth. All measurement data recorded by the application were sent to an Excel spreadsheet for further analysis. The measurement data were then collated with those of hours of work, day of the week, job designation, and workplace recorded by the participants.

### Data analysis

Measurement data obtained between 8:00 and 17:00 were used in the analysis to ensure consistency of the data. No additional data were introduced to adjust for defects in any measurement results. In addition to SBP, DBP, and HR, we also calculated pulse pressure (PP), defined as the difference between SBP and DBP. The SBP, DBP, PP, and HR values are presented as the

| Job                              | Workplace                      |
|---------------------------------|--------------------------------|
| Conference †                   | CT examination room            |
| CT scan for therapeutic planning † | Linac room                     |
| Data analysis †                 | Lunchroom                      |
| Dealing with patients †         | Office                         |
| Dose verification †             | PET examination room           |
| Equipment accuracy control †    | Preparation room for radiopharmaceutical |
| Equipment check †               | Scintigraphy room              |
| Irradiation †                   | Treatment planning room        |
| Preparation of radiopharmaceutical † |                                 |
| Radiotherapy planning †         |                                 |
| Registration of patient data †  |                                 |
| Research †                      |                                 |
| Rest †                          |                                 |
| Scanning †                      |                                 |

* standing job,
† sitting job, CT: computed tomography, PET: positron emission tomography

https://doi.org/10.1371/journal.pone.0276483.t001
mean (± SD), maximum, minimum, and coefficient of variation [CV(%)], each of which was normalized as the ratio to baseline (measurement value divided by the mean baseline value). To evaluate the influence of body position on the measurement data, each job was categorized as a “standing job” or “sitting job”, as shown in Table 1.

Unpaired t-test was used to compare the WD measurement data at 17:00 with the baseline values, and to compare measurement data between sitting and standing jobs. Pearson correlation coefficient (r) was used to evaluate the relationship between the basic measurements obtained by WD and those by medical sphygmomanometer. Bland-Altman plot was used to evaluate the degree of agreement between the basic measurements obtained by WD and those by medical sphygmomanometer.

**Results**

**Comparison of baseline and work time WD measurements**

The difference between the oscillometric type sphygmomanometer and WD were 9 ± 10 mmHg in SBP, 8 ± 6 mmHg in DBP and -3 ± 6 in HR. Correlation between measurements obtained by the oscillometric type sphygmomanometer and WD was r = –0.41 for SBP, r = 0.24 for DBP, and r = 0.79 for HR (Fig 1: upper low). The agreement of measurement results between the oscillometric type sphygmomanometer and WD is graphically depicted with a Bland-Altman in Fig 1 (lower low). Measurements obtained at 17:00 during work time by WD were significantly higher than the baseline measurements (measured at 17:00) for SBP, DBP, and HR (Fig 2).

**Measurement results in individuals**

The measurements obtained in each participant are shown in Tables 2, and 3 shows the ratio to baseline of the mean, max/min, and CV(%) values for each metric, for each participant. The ratio to baseline ranged from 1.02 to 1.26 for SBP and from 1.07 to 1.30 for DBP, and SBP was >130 mmHg in two of the seven participants. The ratio to baseline of CV(%) for SBP and DBP

![Fig 1. Correlation and degree of agreement between measurements obtained by the oscillometric type sphygmomanometer (conventional) and WD. upper low: Pearson correlation coefficient analysis (r and black solid line), lower low: Bland-Altman plot analysis The mean difference is represented by the black solid line with the 95% limits of agreement represented by the dashed lines.](https://doi.org/10.1371/journal.pone.0276483.g001)
was approximately 10% over the total observation term and per day. The ratio to baseline for HR ranged from 0.95 to 1.29, and mean HR was >70 bpm in four of the seven participants. CV(%) of HR was almost the same as that for SBP, DBP, and PP. Among the participants, SBP and DBP values showed similar trends, and thus PP showed little variation. The trends in SBP and DBP for individuals were not consistent with the trends in HR.

Measurement deficit rates

Table 4 shows the measurement deficit rates, which ranged from 17.6% to 37.7% for BP according to work description and from 16.2% to 44.0% by work location. There was minor

Table 2. Measurement result of subjects.

| Index | Participants |
|-------|--------------|
|       | A            | B            | C            | D            | E            | F            | G            |
| SBP   | Average ± SD | 131 ± 14     | 110 ± 2      | 126 ± 2      | 125 ± 2      | 132 ± 13     | 117 ± 15     | 123 ± 15     |
|       | Max/Min      | 181/87       | 119/105      | 182/94       | 170/100      | 201/100      | 183/91       | 177/95       |
|       | CV (%)       | 10.8         | 1.6          | 11.3         | 10.1         | 8.4          | 12.8         | 12.1         |
|       | CV(%) per day| 10.9         | 1.5          | 11.2         | 9.8          | 8.1          | 12.5         | 12.0         |
| DBP   | Average ± SD | 87 ± 9       | 76 ± 1       | 84 ± 9       | 83 ± 8       | 88 ± 7       | 78 ± 10      | 82 ± 10      |
|       | Max/Min      | 118/56       | 81/73        | 119/61       | 110/67       | 132/67       | 120/59       | 115/61       |
|       | CV (%)       | 10.2         | 1.2          | 11.0         | 9.8          | 8.0          | 13.1         | 11.9         |
|       | CV(%) per day| 10.3         | 1.2          | 10.9         | 9.5          | 7.7          | 12.8         | 11.7         |
| PP    | Average ± SD | 44 ± 5       | 34 ± 1       | 42 ± 5       | 41 ± 5       | 44 ± 4       | 39 ± 5       | 41 ± 5       |
|       | Max/Min      | 63/31        | 38/31        | 101/33       | 60/33        | 69/33        | 63/32        | 62/33        |
|       | CV (%)       | 12.4         | 2.9          | 12.4         | 11.0         | 9.4          | 12.6         | 12.9         |
|       | CV(%) per day| 12.5         | 2.8          | 12.1         | 10.7         | 9.0          | 12.3         | 12.7         |
| HR    | Average ± SD | 72 ± 8       | 80 ± 7       | 67 ± 9       | 71 ± 7       | 71 ± 10      | 66 ± 9       | 68 ± 8       |
|       | Max/Min      | 95/58        | 112/65       | 103/55       | 101/58       | 105/58       | 104/49       | 105/56       |
|       | CV (%)       | 10.8         | 9.1          | 14.0         | 10.2         | 14.4         | 13.8         | 11.3         |
|       | CV(%) per day| 8.0          | 7.6          | 10.3         | 9.1          | 10.1         | 11.0         | 10.0         |

SBP: systolic blood pressure, DBP: diastolic blood pressure, PP: pulse pressure, HR: heart rate, CV: coefficient of variation, CV(%) per day: average of CV in each day.
deficit of measurement for HR. There was no deficit of measurement in specific individuals. The deficit rate was 24.1% for sitting jobs and 27.0% for standing jobs.

**Variation in BP and HR by time and day of week**

For BP, the ratio of the mean measurements to baseline was almost 1.15 to 1.2 but was >1.2 at the time of starting work, middle of lunch time, after lunchtime, and at 14:00; and the ratio to

| Table 3. Ratio of measurement result compared to the baseline. |
|---------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Index              | A         | B         | C         | D         | E         | F         | G         |
| SBP Average ± SD   | 1.19 ± 0.13 | 1.02 ± 0.02 | 1.16 ± 0.13 | 1.18 ± 0.12 | 1.19 ± 0.10 | 1.26 ± 0.16 | 1.21 ± 0.15 |
| Max/Min            | 1.65 / 0.79 | 1.11 / 0.98 | 1.67 / 0.87 | 1.61 / 0.95 | 1.80 / 0.90 | 1.97 / 0.98 | 1.74 / 0.93 |
| CV(%)              | 10.8      | 1.6       | 11.3      | 10.1      | 8.4       | 12.8      | 12.1      |
| DBP Average ± SD   | 1.19 ± 0.12 | 1.07 ± 0.01 | 1.16 ± 0.13 | 1.18 ± 0.12 | 1.18 ± 0.09 | 1.30 ± 0.17 | 1.22 ± 0.14 |
| Max/Min            | 1.61 / 0.76 | 1.13 / 1.01 | 1.64 / 0.84 | 1.56 / 0.95 | 1.77 / 0.90 | 2.01 / 0.99 | 1.71 / 0.91 |
| CV(%)              | 10.2      | 1.2       | 11.0      | 9.8       | 8.0       | 13.1      | 11.9      |
| HR Average ± SD    | 1.02 ± 0.11 | 1.17 ± 0.11 | 0.95 ± 0.14 | 1.17 ± 0.12 | 1.09 ± 0.16 | 1.29 ± 0.18 | 1.25 ± 0.14 |
| Max/Min            | 1.34 / 0.82 | 1.63 / 0.95 | 2.30 / 0.77 | 1.66 / 0.96 | 1.62 / 0.88 | 2.01 / 0.95 | 1.93 / 1.01 |
| CV(%)              | 10.8      | 9.1       | 14.0      | 10.2      | 14.4      | 13.8      | 11.3      |

SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, CV: coefficient of variation

https://doi.org/10.1371/journal.pone.0276483.t003

| Table 4. Deficit rates of measurement data by job and workplace. |
|---------------------|------------------|------------------|------------------|
| Group               | Item                                | Deficit rate of BP (%) | Deficit rate of HR (%) |
| Job                 | Preparation of radiopharmaceuticals  | 37.7                  | 2.2               |
|                     | Equipment check                        | 33.9                  | 0                 |
|                     | Registration                           | 28.6                  | 0                 |
|                     | Irradiation                            | 28.1                  | 0                 |
|                     | Rest                                   | 27.1                  | 1.5               |
|                     | CT scan for therapeutic Planning       | 27.0                  | 0                 |
|                     | Scanning                               | 26.3                  | 0                 |
|                     | Dose verification                       | 25.2                  | 0                 |
|                     | Equipment accuracy control             | 24.4                  | 0                 |
|                     | Radiotherapy planning                  | 22.0                  | 0                 |
|                     | Dealing with patients                  | 20.2                  | 0                 |
|                     | Research                               | 21.6                  | 0                 |
|                     | Data analysis                          | 18.8                  | 0                 |
|                     | Conference                             | 17.6                  | 0                 |
| Workplace           | Lunchroom                              | 44.0                  | 5.1               |
|                     | Preparation room for radiopharmaceutical | 31.3              | 2.4               |
|                     | CT examination room                    | 26.5                  | 0                 |
|                     | Linac room                             | 26.5                  | 0                 |
|                     | PET examination room                   | 23.9                  | 0                 |
|                     | Scintigraphy examination room          | 23.7                  | 0                 |
|                     | Office                                 | 23.1                  | 0                 |
|                     | Treatment planning room                | 16.2                  | 0                 |

BP: blood pressure, HR: heart rate, CT: computed tomography, PET: positron emission tomography

https://doi.org/10.1371/journal.pone.0276483.t004
baseline for CV(%) showed a similar trend as the ratio to baseline of the mean values. For HR, the ratio to baseline decreased in the late morning and the CV(%) values were generally stable at all times (Fig 3). The ratios to baseline of SBP and DBP were generally stable, whereas that of HR showed variation according to the day of the week (Fig 4).

**Variation in BP and HR according to job and workplace**

The ratio to baseline for SBP, DBP, and HR was >1.2 for irradiation, equipment accuracy control, registration of patient data, dose verification, and conference time; and was <1.2 for scanning, research, preparation of radiopharmaceuticals, dealing with patients, and data analysis (Fig 5).

The ratio to baseline for SBP, DBP and HR was significantly higher for jobs in the standing position than the sitting position (SBP: standing position 1.23±0.19, sitting position 1.15±0.13, p<0.001, DBP: standing position 1.22±0.14, sitting position 1.17±0.13, p<0.001, HR: standing position 1.18±0.18, sitting position 1.14±0.18, p<0.001). CV(%) was higher in the standing position than the sitting position for SBP, but was similar between positions for DBP and HR (SBP: standing position 15.5, sitting position 11.7, DBP: standing position 11.8, sitting position 11.5, HR: standing position 15.6, sitting position 15.7). The ratio to baseline for SBP, DBP, and HR was higher for the locations of CT examination room, treatment planning room, linac room, and the office, and lower for the lunchroom. The CV(%) values of these metrics were similar for all workplaces (Fig 6). The detailed measurement data according to the day of the week, job, and workplace are provided in S1–S3 Tables, respectively.

**Discussion**

In this preliminary study, we obtained BP and HR of young radiological technologists measured using a WD, and evaluated variation in the values among individuals, and according to the day of the week, job, and workplace. Measurements obtained during work time by WD were significantly higher than those at baseline for SBP, DBP, and HR. The ratio of mean to baseline measurements ranged from 1.02 to 1.26 for SBP, from 1.07 to 1.30 for DBP, and from 0.95 to 1.29 for HR. The ratio of mean BP was >1.2 at the time of starting work, middle of lunch time, after lunch, and at 14:00. The ratio to baseline for SBP, DBP, and HR was >1.2 for irradiation, equipment accuracy control, registration of patient data, dose verification, and
conference time. These values were also higher for the locations of CT examination room, treatment planning room, linac room and the office. CV(%) values of these metrics were generally stable for all workplaces. Measurement of these metrics by WD may be a useful method for evaluating an individual’s unconscious workload.

The WD could record BP and HR measurements periodically with minimal discomfort and without interfering with work. The collection of a large amount of data by WD might enable the discovery of characteristics that lead to present or future pathological conditions. In addition, the simultaneous monitoring of environmental conditions and WD measurement enables detection of values indicative of abnormal condition. Therefore, the shift to the digital approach of monitoring BP and HR is expected to make a significant contribution to the field of preventive medicine [21, 22].

---

**Fig 4. Ratio and CV (%) of SBP, DBP and HR by day of week.**

https://doi.org/10.1371/journal.pone.0276483.g004

**Fig 5. Ratio and CV (%) of SBP, DBP and HR by job.**

https://doi.org/10.1371/journal.pone.0276483.g005
Photoplethysmography (PPG) is a noninvasive optical technique using infrared light and photodiodes to visualize the pressure pulse waves (PWs) in blood vessels by measuring the volumetric changes of pulsating blood and thus the expansion and contraction of the vessels [23, 24]. With the advancement of digital sensors, signal processing, machine-learning algorithms, and improved physiologic models, pulse waveform analysis to assess BP has become feasible [25–29].

However, sensing, biological, and cardiovascular factors can affect PPG recordings. Tissue modifications generated by voluntary movements can create alterations of inner tissues, which leads to modification of receiving light resulting in generating a different signal. Therefore, BP measurement results with WD may be impacted by stationary or not at the moment of BP measurement [30].

It is known that commercially available mobile health devices that record measurements have limited reliability [31], and that a large proportion of devices marketed for BP monitoring have not been sufficiently validated [32]. Our results showed that baseline BP did not correlate highly enough with those obtained by the medical sphygmomanometer. Radial and brachial SBP measurements differ, with average values reported as 5.5 mm Hg higher for radial SBP than brachial SBP [33]. In our study, mean (±SD) SBP (113±6) and DBP (77±4) measured at the left wrist by WD tended to be higher than those measured at the upper arm by a medical sphygmomanometer (104±7 and 69±5, respectively), but the correlation between them was low to modest. In addition, there was a deficit of measurement for SBP and DBP. Therefore, greater accuracy is required in BP measurements obtained with a WD. In contrast, there was good correlation between the device types for HR, with almost no measurement deficit.

Mean SBP and DBP measurements by WD were higher than baseline in all participants and showed difference in CV(%) of approximately 10%. Mean SBP was >130 mmHg in two participants, which is higher than normal. Comparison of measurements obtained at 17:00 revealed that mean BP, PP and HR values were significantly higher than at baseline, which suggests an influence of work-related factors.
Because the baseline measurements showed individual variation in BP and HR, we used the ratio to baseline (measurement value divided by the mean baseline value) to normalize the participants’ data. The measurements for SBP obtained at work were 1.02–1.26 times higher than the baseline values. Job strain appeared to be a trigger for elevation of SBP.

In general, BP tends to be higher in the morning and lower at night, and there is interindividual variation in daytime BP in response to stress [2]. Our study showed that ratio to baseline values for BP were highest at the start of work, lunchtime, start of afternoon work time, and early afternoon. The ratio to baseline values for HR were also highest at the start of work and in the afternoon. This finding suggests that starting work was one of the factors that increased the ratio to baseline values of BP and HR. Day of the week had little influence on the ratio of mean BP to baseline, and a slight influence on HR. Although the season of the year might have an effect on BP, our measurements were all conducted in the summer season and therefore we consider that season would not have affected our data.

In terms of job performed, the ratio to baseline for BP was higher for irradiation, registration of patient data, dose verification and conference time, and lower for research, preparation of radiopharmaceuticals, scanning, and dealing with patients, which was possibly due to the radiological technologist’s body position: BP was higher in jobs performed in the standing position than the sitting position, whereas there was little difference in HR between positions. BP is rarely measured in the standing position; however, SBP has been reported to decrease by approximately 8 mmHg when an individual changes their position from lying to sitting or standing [34, 35]. Another study found no difference in SBP or DBP according to body position in participants in their 20s and 30s, but a difference was found in those in an older age group [36]. Thomas et al. reported a more frequent incidence of hypertension within 8 years in young adults who showed an increase in SBP after changing to the standing position [37]. Based on these results, an increase in SBP while working in the standing position may be a notable finding for monitoring the state of health. In contrast, it has been generally recommended that prolonged sitting during deskwork should be reduced; therefore, investigation of the benefits of a balance of sitting and standing work may be task for the future [38]. The effects of HR monitoring remain unclear because interrupting prolonged sitting leads to a non-significant increase in HR [39]. Other possible explanations for the variation of BP is that BP might be influenced by the jobs that require quick and precise decision-making. In contrast, the body can recover BP during jobs that take longer time. Rest time has a certain effect on stabilizing blood pressure, because the ratio to baseline value for rest time was in the middle of the range among the various jobs. However, it should be understood that moving from rest to working is the point when BP will change largely.

This study has several limitations, which include the small number of participants, and that continuous data collection with large population is still required. The WD used in this study was a commercially available product, and a greater degree of quality control is required regarding accuracy. Our results might have been affected by how the WD was worn, and factors such as tightness on the wrist, slight changes in the position of the WD while working, and skin dryness require investigation in future studies.

Supporting information

S1 Table. Measurement result by day of week.
(DOCX)

S2 Table. Measurement result by job.
(DOCX)
S3 Table. Measurement result by workplace.

(DOCX)

Acknowledgments
We thank Kahori Miyake for contributing to this study.

Author Contributions

Conceptualization: Ryogo Minamimoto, Futoshi Matsunaga.

Data curation: Yui Yamada.

Formal analysis: Ryogo Minamimoto, Yui Yamada.

Funding acquisition: Ryogo Minamimoto.

Investigation: Ryogo Minamimoto, Yui Yamada.

Methodology: Yui Yamada, Kaori Saito, Hironori Kajiwara.

Project administration: Ryogo Minamimoto, Yui Yamada, Futoshi Matsunaga.

Supervision: Ryogo Minamimoto.

Validation: Ryogo Minamimoto.

Writing – original draft: Ryogo Minamimoto.

Writing – review & editing: Yui Yamada, Yasuharu Sugawara, Megumi Fujii, Kazuki Kotabe, Kakeru Iso, Hiroki Yokoyama, Keiichi Kurihara, Tsubasa Iwasaki, Daisuke Horikawa, Kaori Saito, Hironori Kajiwara, Futoshi Matsunaga.

References

1. Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJL. Global and regional burden of disease and risk factors, 2001: Systematic analysis of population health data. Lancet. 2006; 367: 1747–1757. https://doi.org/10.1016/S0140-6736(06)68770-9 PMID: 16731270

2. Georgiou K, Larentzakis AV, Khamis NN, Alsuhailani GI, Alaska YA, Giallafos EJ. Can wearable devices accurately measure heart rate variability? A systematic review. Folia Med. 2018; 60: 7–20. https://doi.org/10.2478/folmed-2018-0012 PMID: 29668452

3. Ahmad S, Ramsay T, Huebisch L, Flanagan S, McDiarmid S, Batkin I, et al. Continuous multi-parameter heart rate variability analysis heralds onset of sepsis in adults. PLoS ONE 2009. 4: e6642. https://doi.org/10.1371/journal.pone.0006642 PMID: 19680545

4. Huang C, Alamili M, Rosenberg J, Gogeurn J. Heart rate variability is reduced during acute uncomplicated diverticulitis. J Crit Care. 2016; 32: 189–195.

5. Perez MV, Mahaffey KW, Hedlin H, Rumsfeld JS, Garcia A, Ferris T, et al. Large-scale assessment of a smartwatch to identify atrial fibrillation. N Engl J Med 2019. 381: 1909–1917. https://doi.org/10.1056/NEJMoa1901183 PMID: 31304404

6. McConnell MV, Shcherbina A, Pavlovic A, Homburger JR, Goldfeder RL, Wagott D et al. Feasibility of obtaining measures of lifestyle from a smartphone app: the MyHeart Counts Cardiovascular Health Study. JAMA Cardiol. 2017; 2: 67–76. https://doi.org/10.1001/jamacardio.2016.4395 PMID: 27973671

7. Avrani S, Tison GH, Aschbacher K, Kuhar P, Vittinghoff E, Butzner M, et al. Real-world heart rate norms in the Health eHeart study. NPJ Digit Med. 2019; 2: 58. https://doi.org/10.1038/s41746-019-0134-8 PMID: 31304404

8. Komori T, Eguchi K, Hoshide S, Williams B, Kario K. Comparison of wrist-type and arm-type 24-h blood pressure monitoring devices for ambulatory use. Blood Press Monit. 2013; 18:57–62. https://doi.org/10.1097/MBP.0b013e32835d124f PMID: 23263936

9. Daskivich TJ, Houman J, Lopez M, Luu M, Fleshner P, Zagliyan K, et al. Association of wearable activity monitors with assessment of daily ambulation and length of stay among patients undergoing major
surgery. JAMA Netw Open. 2019; 2:e187673. https://doi.org/10.1001/jamanetworkopen.2018.7673 PMID: 30707226

10. Vijayan V, Connolly JP, Condell J, McKelvey N, Gardiner P. Review of Wearable Devices and Data Collection Considerations for Connected Health. Sensors 2021, 21, 5589. https://doi.org/10.3390/s21165589 PMID: 34451032

11. Kario K, Tomitani N, Kanegae H, Yasui N, Nishizawa M, Fujiwara T, et al. Development of a new ICT-based multisensory blood pressure monitoring system for use in hemodynamic biomarker-initiated anticipation medicine for cardiovascular disease: the National IMPACT Program Project. Prog Cardiovasc Dis. 2017; 60:435–449.

12. Josep S, Martin P, Fabian B, Nicolas P, Yan D, Christophe V, et al. Continuous non-invasive monitoring of blood pressure in the operating room: a cuffless optical technology at the fingertips. Current Directions in Biomedical Engineering. 2016: 2:267–271.

13. Cesana G, Ferrario M, Sega R, Miledi C, De Vito G, Mancia G, et al. Job strain and ambulatory blood pressure levels in a population-based employed sample of men from northern Italy. Scand J Work Environ Health. 1996; 22:294–305. https://doi.org/10.5271/sjweh.144 PMID: 8881018

14. Fauvel J, Quelin P, Ducher M, Rakotomalala H, Laville M. Perceived job stress but not individual cardiovascular reactivity to stress is related to higher blood pressure at work. Hypertension. 2001; 38:71–75. https://doi.org/10.1161/01.hyp.38.1.71 PMID: 11463762

15. Landsbergis PA, Schnall PL, Pickering TG, Warren K, Schwartz JE. The impact of job strain and marital cohesion on ambulatory blood pressure during 1 year: the double exposure study. Am J Hypertens. 2007; 20:148–153. https://doi.org/10.1016/j.amjhyper.2006.07.011 PMID: 17261459

16. Kario K. Management of hypertension in the digital era: small wearable monitoring devices for remote blood pressure monitoring. Hypertension. 2020; 76:640–50. https://doi.org/10.1161/HYPERTENSIONAHA.120.14742 PMID: 32755418

17. Allen J. Photoplethysmography and its application in clinical physiological measurement. Physiol Meas. 2007; 28:R1–39. https://doi.org/10.1088/0967-3334/28/3/R01 PMID: 17322588

18. van Velzen MHN, Loeve AJ, Niehoff SP, Mik EG. Increasing accuracy of pulse transit time measurements by automated elimination of distorted photoplethysmography waves. Med Biol Eng Comput. 2017; 55:1989–2000. https://doi.org/10.1007/s11517-017-1642-x PMID: 28361357

19. Lee H, Kim E, Lee Y, Kim H, Lee J, Kim M, et al. Toward all-day wearable health monitoring: An ultra-low-power, reflective organic pulse oximetry sensing patch. Sci Adv. 2018; 9;4:eaas9530.26. https://doi.org/10.1126/sciadv.aas9530 PMID: 30430132

20. Chandrasekhar A, Kim CS, Naij M, Natarajan K, Hahn JO, Mukkamala R. Smartphone-based blood pressure monitoring via the oscillometric finger-pressing method. Sci Transl Med. 2018; 10:eaap8674. https://doi.org/10.1126/scitranslmed.aap8674 PMID: 29515001

21. Liang Y, Chen Z, Ward R, Eldergi M. Hypertension assessment using photoplethysmography: a risk stratification tool. J. Clin. Med. 2018; 18:8:12. https://doi.org/10.3390/jcm8010012 PMID: 30577637

22. Liang Y., Chen Z., Ward R. & Eldergi M. Photoplethysmography and deep learning: enhancing hypertension risk stratification. Biosensors 8, 101 (2018). https://doi.org/10.3390/bios8040101 PMID: 30373211
29. Elgendi M, Fletcher R, Liang Y, Howard N, Lovell NH, Abbott D, et al. The use of photoplethysmography for assessing hypertension. NPJ Digit Med. 2019; 2:60. https://doi.org/10.1038/s41746-019-0136-7 PMID: 31388564

30. Castaneda D, Esparza A, Ghamari M, Soltanpour C, Nazarian H. A review on wearable photoplethysmography sensors and their potential future applications in health care. Int J Biosens Bioelectron. 2018; 4:195–202. https://doi.org/10.15406/ijbsbe.2018.04.00125 PMID: 30906922

31. Burke LE, Ma J, Azar KM, Bennett GG, Peterson ED, Zheng Y, et al. Current science on consumer use of mobile health for cardiovascular disease prevention: a scientific statement from the American Heart Association. Circulation. 2015; 132:1157–1213. https://doi.org/10.1161/CIR.0000000000000232 PMID: 26271892

32. Picone DS, Deshpande RA, Schultz MG, Fonseca R, Campbell NRC, Delles C, et al. Nonvalidated home blood pressure devices dominate the online marketplace in Australia: major implications for cardiovascular risk management. Hypertension. 2020; 75:1593–1599. https://doi.org/10.1161/HYPERTENSIONAHA.120.14719 PMID: 32275193

33. Armstrong MK, Schultz MG, Picone DS, Black JA, Dwyer N, Roberts-Thomson P, et al. Brachial and Radial Systolic Blood Pressure Are Not the Same. Hypertension. 2019; 73:1036–1041. https://doi.org/10.1161/HYPERTENSIONAHA.119.12674 PMID: 30905194

34. Eser I, Khorshid L, Gunes U Y, Demir Y. Effect of different body position on blood pressure. Journal of Clinical Nursing, 2007; 16, 137–140.

35. Terent A, Breig-Asberg E. Epidemiological perspective of body position and arm level in blood pressure measurement. Blood Pressure. 1994; 3: 156–163. https://doi.org/10.3109/08037059409102246 PMID: 8069403

36. Song MR, Lee YS. Differences in Blood Pressure according to Body Position by Age Groups. J Korean Biol Nurs Sci. 2011; 13: 238–244.

37. Thomas RJ, Liu K, Jacobs DR Jr., Bild DE, Kiefe CI, et al.: Positional Change in Blood Pressure and 8-Year Risk of Hypertension: The CARDIA Study. Mayo Clinic Proc. 2003; 78:951–958.

38. Barone Gibbs B, Kowalsky RJ, Perdomo SJ, Taormina JM, Balzer JR, Jakicic JM. Effect of alternating standing and sitting on blood pressure and pulse wave velocity during a simulated workday in adults with overweight/obesity. J Hypertens. 2017; 35:2411–2418. https://doi.org/10.1097/HJH.0000000000001463 PMID: 28704258

39. Bates LC, Alansare A, Gibbs BB, Hanson ED, Stoner L. Effects of Acute Prolonged Sitting and Interrupting Prolonged Sitting on Heart Rate Variability and Heart Rate in Adults: A Meta-Analysis. Front Physiol. 2021; 12:664628. https://doi.org/10.3389/fphys.2021.664628 PMID: 34012409