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A big data analysis of fever threshold and vital sign characteristics using tympanic temperature in hospitalized patients

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This study aimed to analyze vital sign characteristics of adult patients admitted at the Tertiary Hospital, and to define fever threshold and average body temperature by examining the tympanic temperatures of all patients. Retrospective medical data were extracted from 9195 patients aged > 21 years admitted to a tertiary hospital for elective surgeries between 2016 and 2020. Data regarding the patients' vital signs during their hospital stay, including tympanic body temperature, heart rate, and respiratory rate, were analyzed according to age, sex, and circadian rhythm. A normal-distribution graph was obtained when all the body temperature results were aligned. The average body temperature measured was 36.91 ± 0.45 °C (average ± standard deviation), indicating a potential fever threshold of 37.81 °C. When the participants were divided into age groups, the average temperature, heart rate, and respiratory rate exhibited parabolic trends. Patients in their 60s exhibited the lowest average temperature (36.88 °C), whereas those in their 50s had the lowest average heart rate (75.82/min) and lowest respiratory rate (19.08/min). Heart rate and respiratory rate tended to increase in elderly people older than 81 years. The average body temperature was greater in women than in men (36.94 ± 0.42 °C vs. 36.89 ± 0.47 °C), while the average heart (75.53 ± 10.04/min vs. 77.31 ± 11.52/min) and respiratory rates (19.13 ± 1.39/min vs. 19.29 ± 2.24/min) were lower in women than in men respectively. According to the time of measurement, the average temperature and heart rate appeared to follow a sinusoidal pattern, suggesting that the circadian rhythm was highest at 1 a.m. and lowest at 8 a.m. Tympanic temperature is a convenient measurement method preferred in hospital settings because it is noninvasive and easier to measure compared to other body parts. To develop an improved device and measurement method in the future, it is necessary to analyze tympanic temperature big data and compare it with past vital sign data or biometric information from other body parts.

Keywords Fever, Body temperature, Respiratory rate, Heart Rate, Circadian rhythm

Fever can be defined as an abnormal increase in body temperature caused by various infectious and noninfectious factors, such as bacteria, viruses, or even emotional factors. The normal body temperature is usually considered to be 37 °C, and significant variations from this range can be indicative of an underlying illness or condition. Detection of elevated temperatures through continuous or regular monitoring enables early diagnosis of various diseases[1,2] and aids physicians in determining the need for further diagnostic measures to assess a patient's condition. Hence, body temperature is among the essential vital sign parameters regularly measured in hospitals.

There are four common methods for measuring body temperature: oral, axillary, tympanic, and rectal. It is crucial to consider the specific body region where the temperature is measured, since temperatures can vary across different parts of the body[3]. Among these different regions, the tympanic method provides an easy, accurate, and comfortable method for measuring fever and is thus generally used in most clinical settings. Tympanic Temperature method has several advantages over traditional methods like oral, rectal, and axillary temperatures: direct measurement of core temperature, rapid measurement, minimal discomfort, simple to operate and require minimal training, non-invasive method. tympanic temperature is less influenced by external factors like recent

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food or drink intake, or clothing. Tympanic temperature method used disposable covers, minimizing the risk of transmitting pathogens between patients, and can be a safer option even for immunocompromised patients.

Currently, measuring body temperature at the ear is the most realistic option, and body temperature is measured at the ear in most parts of the medical world. Infrared rays are used to measure tympanic temperature of the eardrum, and through in-device corrections, final readings are provided to the medical staff. Therefore, concerns may be raised about the accuracy of tympanic temperature measurements compared to absolute temperature measurements. The manufacturer's specifications for acceptable accuracy limits are different for each body temperature measurement device, and the in-device corrections are also different. For ideal body temperature measurements, an infrared thermometer needs to be calibrated by comparing readings at two known temperature points: ice water (0 °C/32°F) and boiling water (100 °C/212°F). Therefore, authors consider using an in-ear thermometer with temperature resistance value measured while in direct contact with the ear canal or non-invasive temperature measurement using the eardrum, without relying on in-device correction, to ensure more accurate temperature readings. In fact, the tympanic temperature method is currently widely used and has accumulated the most measurement data, despite the controversy over the true accuracy and measurement methods. The tympanic temperature big data must be carefully analyzed in order to develop improved devices and measurement methods in the future.

Many studies have been conducted on the various aspects of fever. However, the range of normal body temperature and the standard of fever differ among these studies and are usually based on studies related to specific diseases instead of normal adults in the general population. To our knowledge, the fever threshold, generally thought to be about 37.8 ~ 38 °C, is based on traditional rather than scientific evidence obtained using standardized devices and protocols[4].

Heart rate is the number of times the heart beats per minute and indicates how efficiently the heart pumps blood throughout the body. The normal range of heart rate is 60 to 100 beats per minute (bpm). Respiratory rate is the number of breaths taken per minute, and the normal respiratory rate for a healthy adult at rest is typically 12 to 20 breaths per minute. Age, exercise, medications, medical conditions, and stress all affect changes of heart rate and respiratory rate. Body temperature and heart rates are also known to be heavily affected by the circadian rhythm (an endogenous biological rhythm associated with sleep) and the waking cycle. The circadian rhythm usually follows a 24-h cycle and affects bodily functions, such as hormone release, core body temperature, digestion, and pulmonary function[5,6]. Analyzing vital sign data according to the circadian rhythm will help in more accurate measurement and utilization of biosignals.

The purpose of this study was to analyze the average body temperature using the tympanic temperature and define the fever threshold, and to analyze the measured heart and respiratory rates in patients admitted to a tertiary hospital. In addition, vital signs were analyzed according to age group, sex, and measurement time (circadian rhythm). We aimed to compare and organize the vital sign big data with the traditional definitions of normal body temperature, fever, and circadian rhythm. Big data analysis from body temperature measurements in actual hospital settings will be used as basic data to improve concepts of normal body temperature and fever, and improve body temperature measurement devices in the future.

Materials and methods

Subjects

Retrospective medical data were extracted from hospital medical records (data access date from 2021-6-21). Patients admitted for elective surgery to the otorhinolaryngology department between 2016 and 2020 were included in this study. A total of 166,130 datasets were collected from 10,568 patients. Patients aged < 20 years and those who died were excluded from the study. Information containing false data owing to input errors was also filtered and excluded. The remaining 149,254 datasets were used to examine the demographics and vital signs of 9,195 patients. The demographic information, such as age, sex, height, weight, and vital signs, included body temperature, heart rate, respiratory rate, and systolic and diastolic blood pressure. The study design for sophisticated big data analysis of vital signs of ENT inpatients is described (Fig. 1). A demographic supplementary figure was drawn by dividing and analyzing the inpatient group whose vital signs were measured based on age and gender (supplementary Fig. 1).

Method of analysis

Vital signs were measured indoors after the patient was in a sufficient resting state for at least 5 min. All body temperatures were measured using the tympanic method with a thermometer (Braun Thermoscan IRT 6030; Braun, South Boston, MA, USA), which converted the measured value to its oral equivalent (in-device correction). Heart and respiratory rates were measured using a patient monitoring device (BM7; Bionet, South Korea) with ± 2 bpm and ± 1 bpm accuracy, respectively. After initial filtration, all measured data were classified according to sex, age group, and time of measurement.

Statistical analysis

All values are presented as the mean ± standard deviation (SD). All the statistical analyses were performed using Statistical Package for the Social Sciences software (version 22.0; SPSS Inc., Chicago, IL, USA). One-way analysis of variance was performed to compare the effect of age on each variable, and a paired t tests were used to analyze the data pairs. A polynomial regression model was used to quantify the relationship between the measurement time and each variable. $P < 0.05$ indicated statistical significance. Especially, One-way analysis of variance was performed to compare the effects of age on body temperature, heart rate, and respiratory rate. Tukey's Honest Significant Difference (HSD) Test for multiple comparisons results on whether age has a significant effect on (A) average temperature, (B) heart rate, and (C) respiratory rate. Statistical analysis of the average vital signs is described in detail in supplementary Fig. 2.

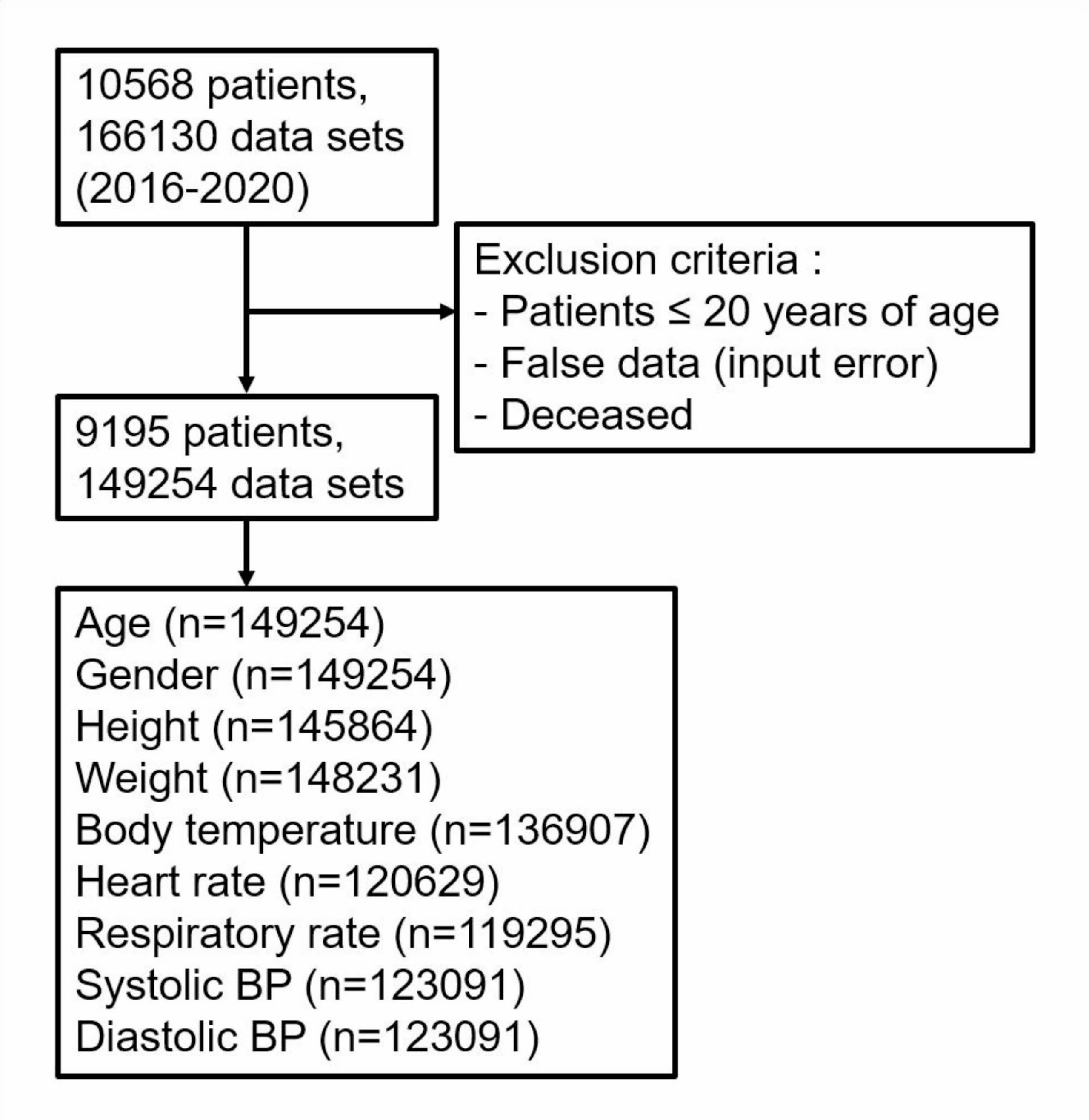


Fig. 1. Study design and protocol used in this study. Datasets ($n=149{,}254$) including demographic data and vital sign information from 9195 patients were included in the study.

Ethics statement

The study protocol followed the guidelines for human studies and was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. The study protocol was reviewed and approved by the Institutional Review Board of Korea University Anam Hospital approved this study (IRB no. 2020AN0527, start date: 2020-11-26). All data used in the study were fully anonymized before assessment, and all methods were performed in accordance with the relevant guidelines and regulations.

Informed consent

We declared that patient electronic data was maintained with confidentiality and all the process complies with the requirements of the Ethics Committee of Anam Hospital of Korea University Medicine. Due to the retrospective nature of the study, the Ethics Committee of Anam Hospital of Korea University Medicine waived the need to obtain Informed consents. In addition, this study is exempted from researcher consent. The reason is that the risk expected in the study is not greater than the risk of LEVEL 1 and the risk to the subject is extremely low, and due to the nature of big data research, it is realistically impossible to obtain consent from all research subjects.

Results

The vital signs characteristics (149,245 data sets) of 9,195 patients aged > 21 years admitted to the Tertiary Hospital Otolaryngology Department for elective surgery between 2016 and 2020 were analyzed (Fig. 1). In this study, 46.36% and 53.64% of the total patients were women and men, respectively. The average age of the participants was 54.05 ± 16.78 years. The average height and weight were 164.75 ± 26.96 cm and 64.78 ± 14.51 kg, respectively. The mean body mass index was 24.17 ± 23.66 kg/m^2. The average body temperature was 36.91 °C ± 0.45 °C (MAX: 40.7 °C, MIN: 33.1 °C), and the average pulse and respiratory rate were 76.6 ± 11.04/min and 19.25 ± 2.42/min, respectively. The average systolic blood pressure was 123.83 ± 15.07 mmHg, and the average diastolic blood pressure was 76.39 ± 10.02 mmHg (Table 1).

The body temperature of all patients exhibited a normal distribution, with a standard deviation of 0.45. To differentiate between febrile and nonfebrile patients, we included all body temperature data, including those of patients with diseases known to cause fever. When establishing a standard for defining fever, the main purpose of differentiating individuals with abnormal body temperatures from normal inpatients must be considered. In screening scenarios, the test sensitivity should meet a certain level; this ensures that patients undergo appropriate early diagnostic evaluations to detect potential underlying diseases. Test specificity is also important for identifying patients who are actually ill. Therefore, it is important to carefully consider the reference range for normal body temperature. The standard definition of the reference range is the interval within which 95% of the reference population falls. Because body temperature in our study followed a normal distribution and because the sample size was sufficiently large, we could assume that a normal body temperature would fall within two standard deviations from either side of the mean. Therefore, we have determined that a suitable threshold for fever incidence should be the upper limit of the 95% confidence interval (CI), which is 37.81 °C. This aligns with the commonly accepted textbook definition of fever (Fig. 2).

When analyzing patients with fever, the most common cases were (1) chronic tonsillitis performing tonsillectomy (12.6%), (2) chronic sinusitis with nasal polyp (9.9%), and (3) malignant neoplasm of thyroid gland (9%). The highest probability of fever by disease was (1) retropharyngeal and parapharyngeal abscess (41.9%), (2) open wound of neck (36.4%), and (3) infectious mononucleosis or Kikuchi disease (25%).

The average temperature, heart rate, and respiratory rate of all enrolled patients were recorded and analyzed according to the age group (Fig. 3A). The average temperatures (°C) were 36.96 ± 0.47, 36.94 ± 0.47, 36.90 ± 0.43, 36.89 ± 0.44, 36.88 ± 0.43, 36.91 ± 0.45, and 36.96 ± 0.49 in those in the 20s, 30s, 40s, 50s, 60s, 70s, and 80s, respectively. The average heart rate (beats/min) was 77.01 ± 10.34, 78.00 ± 11.52, 75.95 ± 9.59, 75.82 ± 10.57, 76.40 ± 11.09, 76.23 ± 11.42, and 79.52 ± 14.17 in those in their 20s, 30s, 40s, 50s, 60s, 70s, and 80s, respectively. The average respiratory rate (/min) was 19.31 ± 1.76, 19.40 ± 2.34, 19.20 ± 2.54, 19.08 ± 2.08, 19.15 ± 2.07, 19.08 ± 2.28, and 20.60 ± 5.03 in those in their 20s, 30s, 40s, 50s, 60s, 70s, and 80s, respectively. The average temperature demonstrated a parabolic trend, with the body temperature being the lowest in those aged between 61 and 70 years (Fig. 3B). The average heart rate was lowest in those aged 51–60 years, and a tendency for the heart rate to increase was observed in those either younger or older than their 50s (Fig. 3C). The average respiratory rate also demonstrated a parabolic trend, with breathing rates being the lowest in those aged 51–60 years (Fig. 3D). The statistical analysis of the average vital signs by age group is described in detail in Supplementary Fig. 2. The largest difference in the average vital signs was calculated by age group: body temperature was 0.08 °C, heart rate was 3.7/min, and respiratory rate was 1.52/min. Considering these findings, the average vital signs according to age group are believed to be similar, and there are likely to be individual differences.

	Total number of patients (*n* = 9195)	
Gender	Female	4263 (46.36%)
	Male	4932 (53.64%)
	Average ± SD	
Age (yr)	54.05 ± 16.78	
Height (cm)	164.75 ± 26.96	
Weight (kg)	64.78 ± 14.51	
BMI (kg/m^2)	24.17 ± 23.66	
Body temperature (℃)	36.91 ± 0.45	
Pulse (/min)	76.60 ± 11.04	
Respiratory rate (/min)	19.25 ± 2.42	
Systolic BP (mmHg)	123.83 ± 15.07	
Diastolic BP (mmHg)	76.39 ± 10.02	

Table 1. Patient characteristics. A total of 9,195 patients were included (46.36% women and 53.64% men). The average body temperature was 36.91 ± 0.45 °C, and the average pulse and respiratory rate were 76.6 ± 11.04/min and 19.25 ± 2.42/min, respectively. SD = standard deviation.

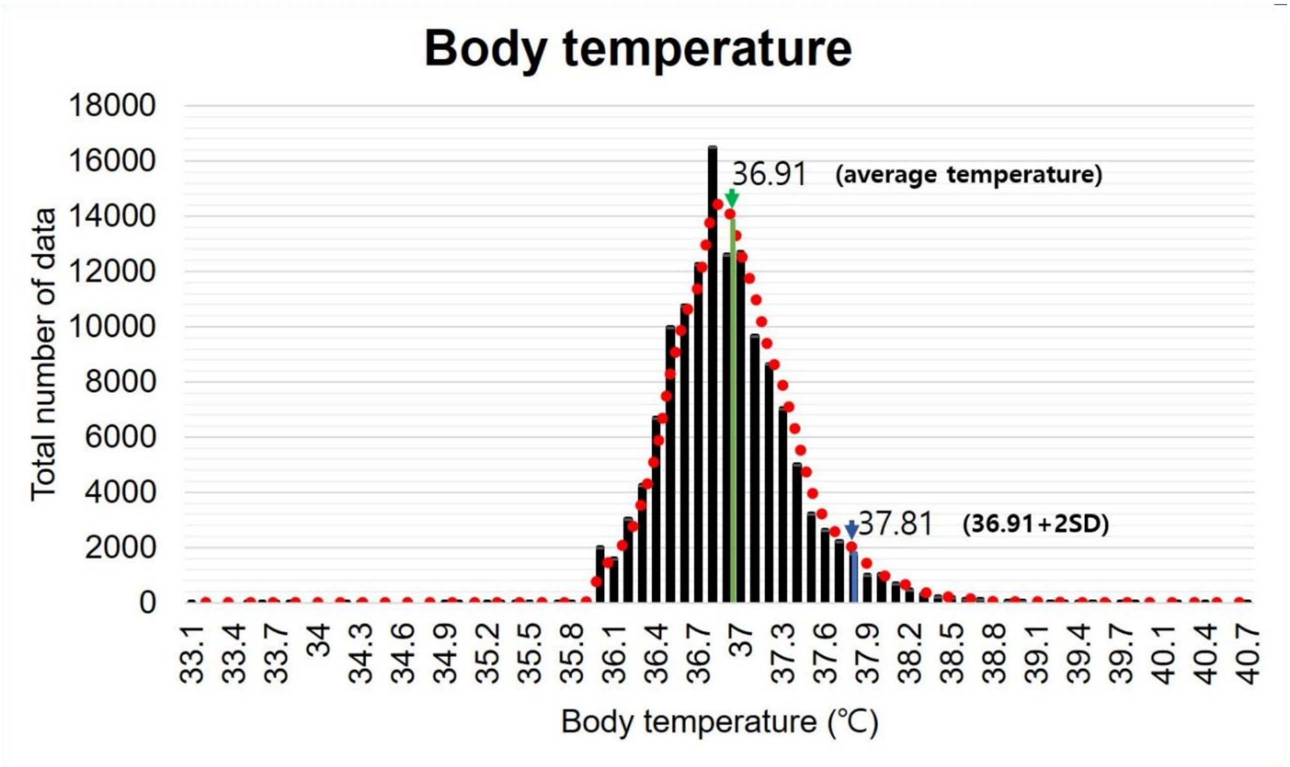


Fig. 2. Body temperature of admitted patients. The average body temperature, which is indicated by the green line, was 36.91 °C with a standard deviation of 0.45. The blue line indicates the upper limit of 95% confidence interval (CI) at 37.81 °C (fever threshold).

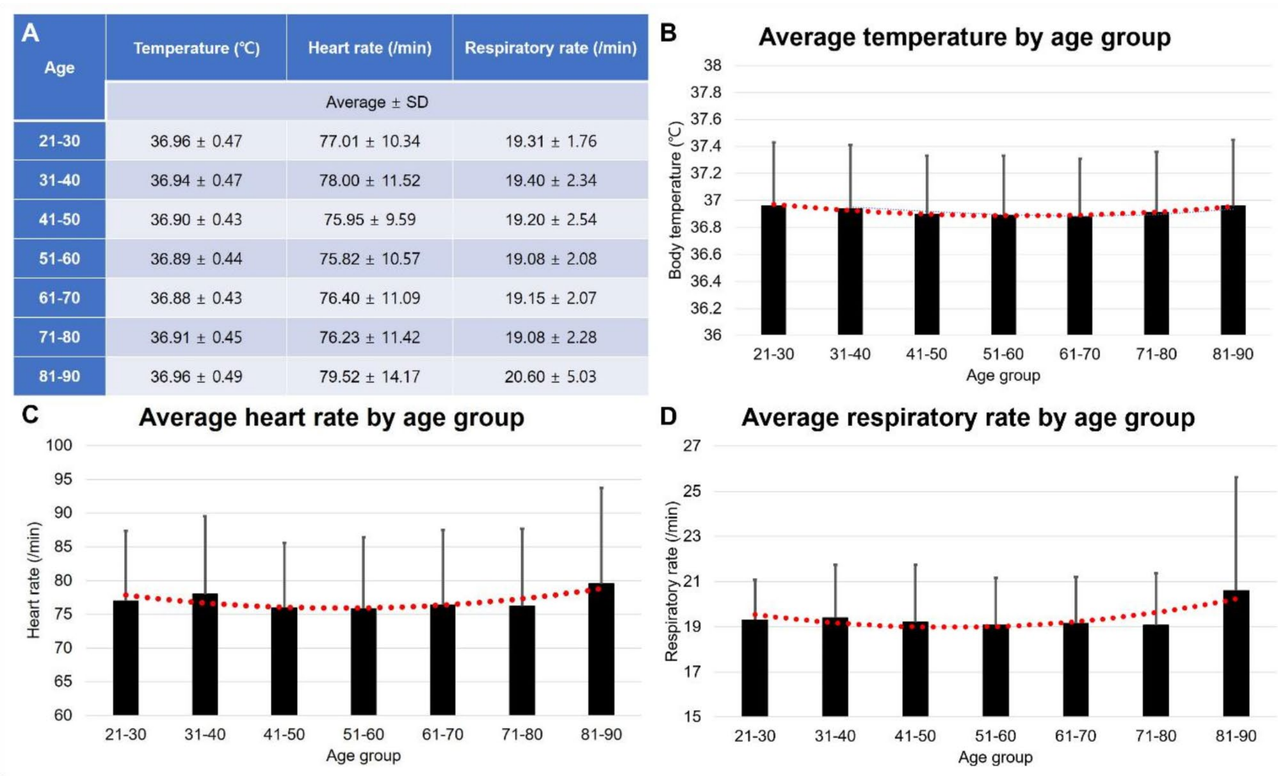
The average temperature, heart rate, and respiratory rate were analyzed according to sex (Fig. 4A). A t-test was performed to compare vital sign measurements between the two groups. There was a significant difference in temperature (°C) between men (36.89 ± 0.47) and women (36.94 ± 0.42) ($p < 0.000$) (Fig. 4B). There was the significant difference in the heart rate (beats/min) between men (77.31 ± 11.52) and women (75.53 ± 10.04) ($p < 0.000$) (Fig. 4C). There was a significant difference in the respiratory rate between men (19.29 ± 2.24) and women (19.13 ± 1.39) ($p < 0.000$) (Fig. 4D). Thus, the average body temperature was significantly greater in women than in men. The average heart and respiratory rates were significantly lower in women than in men.

Finally, the average temperature, heart rate, and respiratory rate of the patients were determined according to the time of measurement (Fig. 5A). The measurements were divided into hourly intervals. The average temperature and heart rate each appeared to follow an oscillatory pattern within a 24-h cycle. A polynomial regression model was used to quantify the relationship between the measurement time and each of the three vital sign measurements. The relationship between the measurement time and body temperature best fit a cubic curve (R square = 0.613, $p < 0.000$) (Fig. 5B), as did the relationship between the measurement time and heart rate (R square = 0.602, $p < 0.000$) (Fig. 5C). Moreover, there was no significant relationship between the measurement time and respiratory rate (Fig. 5D).

Discussion

Body temperature. Many vital sign measurements devices with various features, have been developed to allow users to check and continuously monitor their real-time physical states. The tympanic method provides a noninvasive and relatively easy way to measure body temperature, and many smart devices equipped with sensors that measure body temperature using the tympanic method are being developed.

There are various ways to measure the core body temperature. The rectal method is generally considered one of the most accurate ways of measuring core body temperature and is currently used in intensive care units, where monitoring vital signs is a crucial aspect of patient care (a normal range: 36.4 °C ~ 37.6 °C). Although accurate, the rectal method is invasive and causes embarrassment and discomfort in patients; therefore, its use is limited to conscious patients or the general population. It also takes a relatively long time to reflect rapid temperature changes and is therefore unsuitable for applications in devices aimed at monitoring real-time body temperature for screening purposes[6,7]. Armpit temperature is a measurement taken in the armpit, and normal armpit temperature is usually 35.9 °C to 36.7 °C. Armpit temperature is affected by skin, sweat, and clothing, and your hands are not free. Sublingual temperature measurements had a normal range of 36.2 °C ~ 37.7 °C. Compared to the tympanic temperature, the sublingual temperature is said to be 0.21 °C lower (37.54 ± 0.93 °C vs. 37.33 ± 0.71 °C)[8]. The tympanic method appears to be superior to sublingual method, because the thermometer must be placed in the mouth (for hygienic reasons and because of the consumption of food and beverages



Age	Temperature (°C)	Heart rate (/min)	Respiratory rate (/min)
	Average ± SD		
21-30	36.96 ± 0.47	77.01 ± 10.34	19.31 ± 1.76
31-40	36.94 ± 0.47	78.00 ± 11.52	19.40 ± 2.34
41-50	36.90 ± 0.43	75.95 ± 9.59	19.20 ± 2.54
51-60	36.89 ± 0.44	75.82 ± 10.57	19.08 ± 2.08
61-70	36.88 ± 0.43	76.40 ± 11.09	19.15 ± 2.07
71-80	36.91 ± 0.45	76.23 ± 11.42	19.08 ± 2.28
81-90	36.96 ± 0.49	79.52 ± 14.17	20.60 ± 5.03

Fig. 3. Average temperature, heart rate, and respiratory rate of admitted patients according to age group. **(A)** The average temperature (°C), heart rate (beats/min), and respiratory rate (/min) in different age groups. **(B)** The average temperature demonstrated a parabolic trend, with body temperature being lowest in those aged between 61 and 70 years. **(C)** The average heart rate was lowest in those aged between 51 and 60 years, and a tendency for the heart rate to increase was observed in those either younger or older than their 50s. **(D)** The graph depicting the average respiratory rate demonstrates a parabolic shape with breathing rates being lowest in those aged between 51 and 60 years. Overall, vital signs were generally lowest in those aged between 51 and 70 years.

considerations) and because of the lack of cooperation among children. There is a method of measuring core body temperature using an endotracheal tube in patients under general anesthesia in the operating room, and this method seems promising for research. A comparative study with the tympanic method appears to be necessary in the future.

Many studies have been conducted to evaluate whether the tympanic method is suitable for replacing the rectal method for measuring core body temperature. It is generally known that body temperature measured using the tympanic method is slightly lower than that measured using the rectal method. Aadal et al.[7] reported a linear relationship between rectal and tympanic temperatures. Chamberlain et al. reported that the tympanic method for examining body temperature effectively reflects rapid changes in core body temperature[6]. The tympanic membrane is anatomically located close to the internal carotid artery and is surrounded by highly perfused tissue, making it a promising site for the direct measurement of core body temperature. However, direct contact with the tympanic membrane can cause severe pain, discomfort, and complications such as traumatic external auditory canal laceration or perforation of the tympanic membrane, which is why temperature is measured using the tympanic membrane is performed in a noncontact manner.

Our data hold significant value because they contribute to the existing knowledge by providing average temperature data and fever threshold for adults, obtained through a big data study utilizing the tympanic method. To the best of our knowledge, this large-scale study is the first to measure the body temperature and scientifically define fever using the tympanic method, which is the most commonly used method in tertiary hospitals. According to our results, body temperature followed a standard distribution graph, with an average of 36.91 ± 0.45 °C (fever threshold: 37.81 °C). Normal body temperature and fever threshold in adults has been investigated in various studies (Table 2). The average body temperature was lowest in a study by Vardasca et al.[9] (36.4 °C) and was highest in a study by Casa et al.[10] (36.95 °C). the fever threshold was lowest in a study by Chamberlain et al.[6] (37.31 °C) and was highest in a study by Han et al. (37.81 °C). In the reference studies, the average body temperature was 36.6 °C and the average fever threshold was about 37.5 °C. Because they are hospitalized patients, the number of patients with fever may be greater than that of healthy subjects, so one may mistakenly believe that the average body temperature in this study may be higher than in other studies. When analyzing the middle 95% of patients, excluding febrile and hypothermic patients who fall within 2SD above and

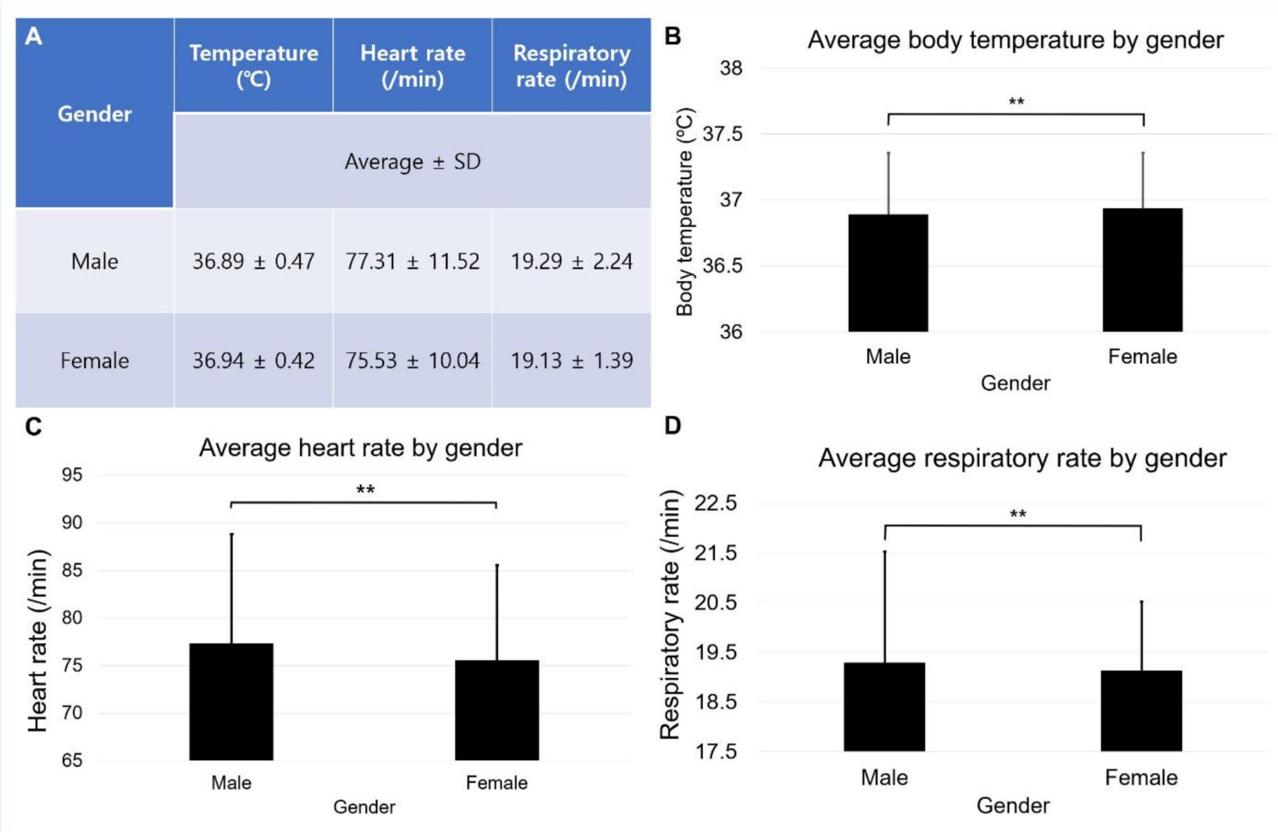


Fig. 4. Average temperature, heart rate, and respiratory rate of admitted patients according to sex. **(A)** The average temperature (°C), heart rate (beats/min), and respiratory rate (/min) by sex. **(B)** The average body temperature was significantly greater in women than in men. **(C)** The average heart rate was significantly lower in women than in men. **(D)** The respiratory rate was significantly lower in women than in men. **Statistically significant.

below the normal distribution of patient groups, the average body temperature was found to be 36.89 ± 0.37 °C, which is similar to the existing 36.91 °C.

The present study had the largest number of participants among all the previous studies, with a total of 9,195 participants. A study by Chamberlain et al. categorized people into age groups, similar to our study. Similarly, they found that the body temperature seemed to stabilize as age increased. However, they found that the average body temperature was the lowest in those aged 76–85 years and that the average body temperature increased in those aged > 85 years. The results of this study indicated that the average body temperature was the lowest in patients in their 60s. Until this point, body temperature generally decreased as age increased but increased in individuals older than 70 years. These results agree with those of a previous study by Chamberlain et al., who also analyzed body temperature according to age group[6]. Another study reported that as patients age, their body temperature decreases owing to decreased metabolic rates[3]. This difference may be due to the inclusion of an elderly population aged > 70 years, similar to the study by Chamberlain. People over 71 are more likely to have underlying health conditions and their vital signs are more likely to be unstable.

In the present study, the average body temperature tended to be greater in women than in men. Studies on the differences in body temperature according to sex have been conducted, and the results have varied widely. Some studies have reported no significant difference in temperature between the sexes[3], while others have reported a greater average body temperature in women[6]. Differences in body temperature according to sex can be explained by previous findings, indicating that body temperature is influenced by fat percentage and skin thickness[11]. Nevertheless, the number of participants was significantly greater in this study, indicating that the results are probably more accurate than those of previous studies.

Heart rate and respiratory rate. Heart and respiratory rates were mostly lowest in middle-aged patients aged between 51 and 70 years. This finding is similar to previous findings in patients aged < 70 years, in which the average body temperature decreased with increasing age[3]. As metabolic rates decrease in elderly patients, it generally makes sense that heart and respiratory rates decrease as age increases. In the present study, heart and respiratory rates increased in patients aged > 70 years. Hospitalized patients over 71 years of age require elective surgery or treatment due to underlying diseases. Therefore, it is assumed that patients over 71 years of age are more likely to have unstable heart and respiratory rates.

A Measurement time	Temperature (°C)	Heart rate (/min)	Respiratory rate (/min)
	Average ± SD		
00	37.18 ± 0.49	84.04 ± 16.85	19.43 ± 4.19
01	37.29 ± 0.55	85.46 ± 16.94	19.51 ± 4.48
02	37.21 ± 0.54	83.55 ± 16.81	19.48 ± 4.33
03	37.26 ± 0.57	84.14 ± 17.93	19.12 ± 4.89
04	37.24 ± 0.60	84.86 ± 17.40	19.40 ± 4.58
05	37.03 ± 0.50	78.85 ± 13.52	19.18 ± 4.80
06	36.88 ± 0.50	80.19 ± 13.66	19.68 ± 2.80
07	36.94 ± 0.54	77.30 ± 14.05	19.32 ± 2.90
08	36.75 ± 0.34	75.50 ± 9.53	19.25 ± 1.75
09	36.96 ± 0.56	78.07 ± 14.89	19.54 ± 3.28
10	36.89 ± 0.51	77.56 ± 13.36	19.43 ± 3.12
11	36.92 ± 0.50	78.00 ± 13.03	19.45 ± 3.05
12	36.95 ± 0.51	78.24 ± 13.39	19.49 ± 2.82
13	36.96 ± 0.49	78.72 ± 13.40	19.59 ± 5.03
14	37.01 ± 0.50	79.17 ± 12.81	19.35 ± 2.47
15	36.98 ± 0.52	79.76 ± 13.11	19.47 ± 2.68
16	37.00 ± 0.50	81.03 ± 13.64	19.65 ± 3.09
17	36.88 ± 0.36	76.00 ± 9.48	19.23 ± 1.69
18	37.16 ± 0.55	80.15 ± 13.36	19.44 ± 2.97
19	37.24 ± 0.56	82.72 ± 14.67	19.67 ± 3.55
20	37.27 ± 0.54	83.68 ± 15.13	19.49 ± 3.69
21	37.24 ± 0.52	81.96 ± 13.96	19.28 ± 3.10
22	37.07 ± 0.46	78.96 ± 12.31	19.06 ± 2.38
23	37.23 ± 0.52	84.16 ± 15.87	19.69 ± 4.14

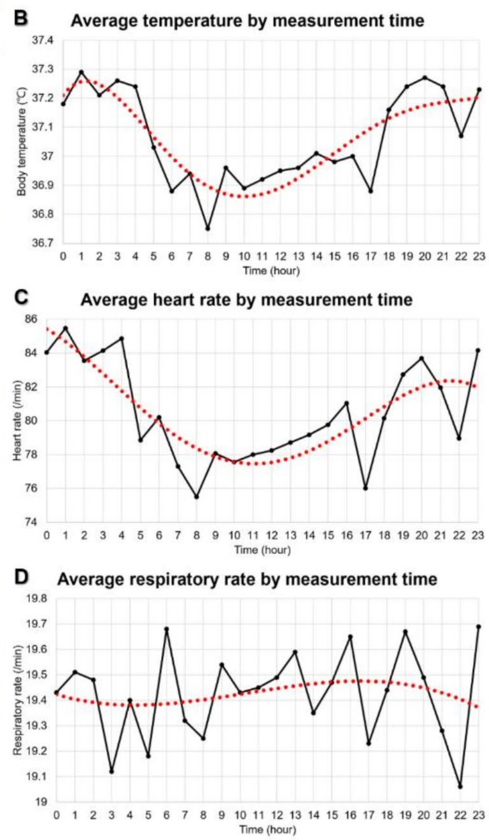


Fig. 5. Average temperature, heart rate, and respiratory rate of admitted patients according to the time of measurement. **(A)** The measured biosignals were divided into hourly intervals, allowing for analysis of the data across a 24-h period. the circadian rhythm was highest at 1 a.m. and lowest at 8 a.m. **(B)** Body temperature increases during the day and decreases during the night while sleeping; in particular, at 8 a.m., the body temperature typically drops. **(C)** Heart rate shows a circadian rhythm similar to body temperature. In particular, the heart rate drops most at 8 a.m. **(D)** The respiratory rate does not show a specific circadian rhythm and is a constant pattern throughout the day.

Previous studies on resting heart rate have focused on the causative relationships between heart rate and various diseases, especially cardiogenic diseases. The normal resting heart rate of healthy individuals in the general population has not been studied; however, it is generally thought to be < 70/min in men and < 80/min in women[12]. Values between 60 and 100 beats per minute are generally considered acceptable and are not related to the acute pathological state. In our study, the heart rate was lower in women than in men. The average resting heart rate was 76.6 beats per minute (77.29/min in men and 75.52/min in women). Because heart rate can be influenced by a variety of factors, including age, sex, individual muscle mass, and time of measurement, our findings were, in a general sense, in agreement with previously existing knowledge on normal resting heart rate. A meta-analysis of heart rate according to sex conducted by Koenig et al. reported that the mean resting heart rate was greater in women than in men[13], which differs from the results of this study. It has also been previously reported that tachycardia is related to a higher mortality rate[14] and that women are expected to live longer and are at a lower risk of cardiovascular disease. The difference between the sexes was small (smaller than the patient-monitoring device accuracy of ± 2 bpm). However, we obtained statistically significant results because of the large number sample size ($n = 149{,}254$).

In this study, the average respiratory rate was 19.15 ± 1.90 in women and 19.35 ± 2.71 in men, which was lower in women than in men. This result is in line with previous studies conducted by Natarajan et al.[15] However, the average respiratory rate itself was greater, whereas Natarajan et al. reported a mean respiratory rate of 15.4 ± 2.35. The respiratory rate can be affected by many factors, including psychological distress or physical exertion. Although the respiratory rate was measured in a resting state, it is predicted that the respiratory rate may have been high in hospitalized patients due to stress during hospitalization or tension at the hospital.

Circadian rhythm. Humans are endothermic and homeothermic. Daily and seasonal temperature changes are controlled by endogenous processes, thereby allowing animals to maintain a relatively stable body temperature. This endogenously controlled variation in body temperature follows an oscillatory pattern during a 24-h cycle and is commonly known as the circadian rhythm. Therefore, the core body temperature is an important indicator of the circadian rhythm and metabolic state of the body. The heart has an endogenous

Author	N	Demographics	Average Body Temperature (Tympanic Method)	Fever (°C)
Basak (2013)	452	Healthy subjects, average age 19.66 ± 0.94 (44.9% male, 55.1% female)	36.78 ± 0.39 °C	37.56
Casa (2007)	25	Average age 26.5 ± 5.3 (15 male, 10 female)	36.95 ± 0.30 °C	37.55
Chamberlain (1995)	1035	Age 16–65	36.55 ± 0.44 °C	37.43
	180	Age 66–75	36.46 ± 0.43 °C	37.32
	149	Age 76–85	36.4 ± 0.48 °C	37.36
	168	Age > 85	36.51 ± 0.46 °C	37.43
	1532	All	36.51 °C	-
Vardasca (2019)	206	Average age 23.2 ± 8.6 (102 male, 104 female)	36.4 ± 0.5 °C	37.4
Geneva (2019, review)	7636	Healthy subjects older than 18 (not gender reported)	36.64 °C ± 0.44 °C	37.52
Han (2024 in this study)	9195	Patients admitted for elective surgeries older than 21 (4932 male, 4263 female)	36.91 ± 0.45 °C	37.81

Table 2. Average body temperature mentioned in various previous studies. The average body temperature was lowest in a study by Vardasca et al.[9] (36.4 °C) and was highest in a study by Casa et al.[10] (36.95 °C). The fever threshold was lowest in a study by Chamberlain et al.[6] (37.31 °C) and was highest in a study by Han et al. (37.81 °C). In the reference study, the average body temperature was about 36.6 °C ($n = 10$) and the average fever threshold was about 37.5 °C ($n = 9$).

peripheral clock. Oscillatory patterns have been observed in intact hearts and isolated tissues. Heart rates are normally greater in the active daytime and lower during the sleeping night[16], as demonstrated in this study and a study by Black et al., in which the heart rate was continuously monitored in healthy individuals[17].

In a controlled laboratory setting without the influence of sleep, Spengler et al. reported that the circadian rhythm has a minimal effect on the respiratory rate[5]. Our study showed similar results, as both body temperature and heart rate exhibited clear diurnal patterns, with the lowest values observed at approximately 8 a.m. and the highest values occurring at approximately 1 a.m. However, regarding the respiratory rate, it was difficult to identify a distinct pattern in its fluctuations over time in this study. The average temperature and heart rate followed an oscillatory circadian rhythm-like pattern when analyzed according to the time of measurement. This pattern was less evident in the hourly respiratory rate measurements. The results of this study confirmed previous findings that some vital signs are more or less influenced by an endogenous clock, and are elevated during the wake periods of the day, followed by a decrease during sleep[18]. Although the differences were small, there was indeed a clear fluctuating pattern of vital signs when vital signs were measured during the 24-h period, which should be considered when assessing patients based on these parameters.

This study provides valuable information about various factors that must be considered when interpreting biosignal data, such as age, gender, and biological rhythm, especially using artificial intelligence (AI) analysis. Since it is difficult for humans to manually calculate the volatility of vital signs according to circadian rhythm, it is expected that artificial intelligence big data analysis of vital signs and easier continuous monitoring will be implemented and developed in the future. The tympanic area, including the external auditory canal, is an easily accessible and promising site where vital signs such as body temperature, heart rate, respiratory rate, and oxygen saturation can be measured with a single device. This study provides baseline data for the development and adjustment of a novel in-ear vital sign measuring device.

Limitations and future suggestions. There is a potential selection bias in this study in that it only includes patients from a single tertiary hospital, which may limit the applicability of the results to other settings or populations. In clinical practice, vital signs are mainly measured by ward nurses, but it is difficult for nurses to measure them frequently during busy work hours. In the future, the ideal temperature measurement will be (1) patient self-monitoring, (2) easy and accurate in-ear vital sign check, (3) real-time electronic medical records (EMR) recording using Bluetooth or WiFi, (4) automatic monitoring check using AI analysis and warning potential risk to medical staff. In the future, vital signs check-up will need to be an advanced form, rather than a ceremonial task, and for this to happen, appropriate medical fees need to be set.

Conclusion

The average body temperature measured was 36.91 ± 0.45 °C (average ± SD), indicating a potential fever threshold of 37.81 °C (average + 2SD). The average pulse was 76.60 ± 11.04/min and respiratory rate was 19.25 ± 2.42/min. Heart rate and respiratory rate tended to increase in elderly people older than 81 years. The average body temperature was greater in women than in men (36.94 ± 0.42 °C vs. 36.89 ± 0.47 °C), while the average heart (75.53 ± 10.04/min vs. 77.31 ± 11.52/min) and respiratory rates (19.13 ± 1.39/min vs. 19.29 ± 2.24/min) were lower in women than in men respectively. Depending on the time of measurement, the average body temperature and heart rate were found to follow a sinusoidal pattern, and the circadian rhythm was highest at 1 a.m. and lowest at 8 a.m. In the future, big data obtained by measuring vital signs in an actual hospital environment can be used as basic data to develop a new in-ear real-time biosignal measurement device that can measure tympanic temperature.

Data availability

The datasets generated and/or analyzed during the current study have been displayed, are provided as supplementary files or are available from the corresponding author on a reasonable request.

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Author contributions

G.J. IM conceptualized the study; G.J. IM applied for funding and coordinated the study and the writing of the manuscript; G.J. IM and H.M. Han wrote the main manuscript text; G.J. IM and H.M. Han coordinated patient recruitment and sample selection; H.M. Han interpreted the data and provided the figures and tables; H.M. Han wrote the methods; G.J. IM wrote the results and discussion; and all authors reviewed the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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