

A Survey on Blood Pressure Measurement Technologies: Addressing Potential Sources of Bias

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Abstract—Blood pressure is a vital sign that offers important insights into overall health, particularly cardiovascular well-being. It plays a critical role in medical settings and homes for disease prevention, diagnosis, treatment, and management. Physicians heavily rely on blood pressure values for making crucial decisions. Most commercial devices utilize cuffs for blood pressure measurement, and automatic devices have gained popularity due to the high prevalence of hypertension. Self-measurement and home monitoring of blood pressure are also recommended. However, concerns arise regarding the accuracy of blood pressure measurement technologies and the alignment of reported values with actual values. People often adjust their medication based on these reported values, making accuracy vital. This study focuses on the concept of “bias” to highlight potential discrepancies between reported and actual blood pressure values. Previous research has identified biases originating from three categories: (1) blood pressure measurement devices, (2) subject-specific factors, and (3) measurement sessions. Specifically, this study examines biases associated with cuff-based blood pressure technologies due to their widespread use in medical applications and the growing trend of home monitoring. Identifying and addressing the primary sources of biases is crucial to prevent their propagation and mitigate potential consequences. Additionally, the study explores the future prospects of blood pressure monitoring using machine learning methods.

I. INTRODUCTION

In 2021, the World Health Organization (WHO) reported that 32% of the world’s mortality is related to cardiovascular diseases (CVDs) [1]. In 2020, CVDs were the leading cause of death in the United States, surpassing cancer and COVID-19 [2]. Strokes and heart attacks are the leading causes of CVD-related mortalities [1]. Hypertension is the most significant risk factor for CVDs; because it rarely shows early symptoms before causing severe damage to organs such as the heart, blood vessels, brain, eyes, and kidneys. Therefore, it is known as the “silent killer” [3], [4]. Monitoring the blood pressure (BP) is one of the effective and widely accessible methods for diagnosing and reducing CVD prevalence [5]. Abnormal BP is even more critical and life endangering for vulnerable populations, including the elderly and pregnant women.

BP is measured manually and automatically in medical centers. Most commercial BP devices are use a *cuff*— a non-elastic fabric commonly wrapped around the arm — to apply sufficient external pressure on the artery wall to temporarily block the blood flow and to measure the BP when the arterial blood pressure and the monitored external pressure are balanced. Over the decades, Cuff-based BP devices have evolved from manual mercury-based devices to

the current ones based on pressure sensors and automatic electronic measurements.

The technology has passed the test of time, due to its simple operation, low-cost, availability and ease of interpretation [6]. Automatic and portable BP devices have also enabled out-of-clinic ambulatory BP monitoring by patients and their families. Although ambulatory BP is not always as accurate as in-clinic measurements, it can be acquired more frequently, reduces clinic visits and costs, increases patients’ satisfaction and overcomes their clinical environment stress, which leads to the so-called *white-coat* hypertension [7]. Specifically, latest guidelines advise patients with gestational and chronic hypertension to repeat BP measuring at home [7].

Hypertension diagnosis and the treatment of many other diseases are based on the accurate measurement of the BP. It is therefore critical to assess the accuracy of BP values reported in ambulatory and in-clinic settings [8], [9]. However, most users are unaware or neglectful of the standard BP measurement protocols that should be followed during BP acquisition to acquire accurate BP values. Therefore, BP measurements — even in clinical settings— can be significantly biased and variant due to the measurement circumstances (beyond the patient’s physiological factors). This results in misinterpretations of BP readings and hampers the reliability of this vital sign for clinical diagnosis.

In the past decade, many studies have focused on the notion of bias and its significance in different areas of biomedical research, including bias in false beliefs about the biological differences between various races [10], pain assessment and treatment recommendations [11], medical equipment [12], racial biases in algorithmic diagnosis [13], performance metrics in algorithmic diagnosis [14], and reducing bias in machine learning (ML) for medical applications [15].

In this survey we focus on potential sources of biases in BP measurement, which can influence BP-based diagnosis of hypertensive and hypotensive patients. We will focus on the most popular commercial cuff-based devices, which are currently the most accurate and popular BP devices used for in- and out-patients. They are also used for calibration of cuff-less BP devices. For this, a broad literature survey was conducted in terms of the various factors that can potentially impact BP measurements, including patient-related factors, BP acquisition session circumstances and device-related factors.

The paper is organized as follows: Section II reviews the biophysics of the BP. Section III classifies BP measurement methods. Section IV investigates different validation standards and reviews various commercial BP technologies and their operation principles. Section V presents potential sources of

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bias in BP technologies from different perspectives. Section VI details the significance of studying bias, followed by perspectives for future research on BP. Section VII discusses the impact and limitations of biases on developing cuff-less BP technologies. Finally, Section VIII concludes this study.

II. A REVIEW OF THE BLOOD PRESSURE PHYSIOLOGY

Vital signs and physiological measurements are proxies for assessing the fundamental body functions. The blood pressure (BP) is one of the important clinical parameters measured from the body, together with the vital signs [16]. A regulated blood pressure guarantees timely and adequate supply of blood [17], which is essential for the blood functions: 1) transportation of nutrients, waste, hormones, oxygen and carbon dioxide, 2) regulation of osmotic pressures, temperature, and PH, and 3) protection against infections via white blood cells, antibodies and clots (to prevent excessive blood loss during injuries).

A. Blood pressure definition

Blood flows across the body due to the pressure difference in the arterial system [18]. The BP assesses the mechanical function of the heart (as a pump). It is the force per unit area of the arterial system, commonly measured in millimeters of mercury (mmHg). In healthy subjects, the heart contracts between 60 to 100 times per minute, resulting in a pulsatile and almost periodic pressure wave in the arterial system. The pressure wave's maximum is during *systole*, when cardiac contraction exerts its maximum pressure to the blood and arterial walls. This is when blood is pumped from the heart into the arteries. The lowest pressure corresponds to *diastole*, when the heart is at rest [19]. Therefore, the arterial BP fluctuates between the maximum and minimum levels and damp down to zero through the end of the arterial circulation system, Fig. 1 [20].

Throughout this work we will study the following BP parameters:

- **Systolic blood pressure (SBP)**, or the maximum pressure inside the arteries during cardiac contraction;
- **Diastolic blood pressure (DBP)**, or the minimum atrial pressure during cardiac rest;
- **Mean Arterial Pressure (MAP)**, which is an empirical weighted average of SBP and DBP, to approximate the true BP average using only its maximum and minimum values [21]:

$$MAP = \frac{SBP + 2 \times DBP}{3} \quad (1)$$

B. Factors impacting the blood pressure

Arterial BP values are subjective, and depend on many factors, including physics and physiology of the body, body position, brain activities, digestive activities, muscle activities, neural stimulations, environmental factors (air temperature and audio noise level), smoking, alcohol and coffee consumption, and medications [22], [23]. There are also various biological factors that impact the BP [24], including:

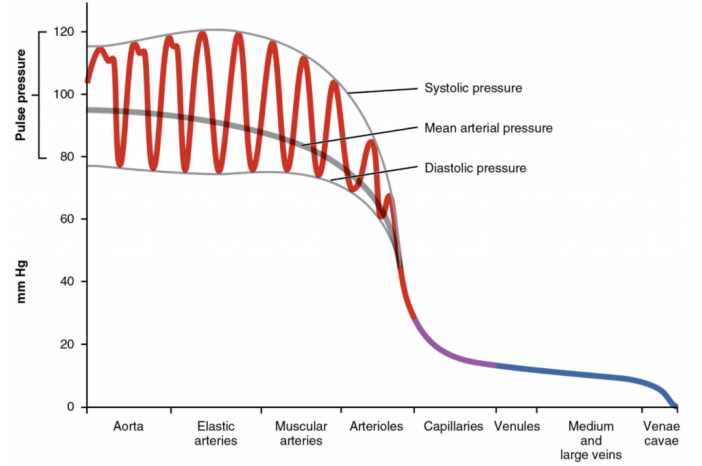


Fig. 1: The systolic, diastolic, mean arterial, and pulse pressures, as well as the overall blood pressure at different points of the blood vessels (Adopted from [20], license (CC-BY-3.0), OpenStax College)

- 1) *Cardiac output*, or the amount of blood that is pumped into the ventricles by the heart. Blood pressure and flow increase when factors such as sympathetic stimulation, epinephrine and norepinephrine, thyroid hormones, and increased calcium ion levels increase cardiac output (heart rate, stroke volume, or both). Conversely, factors that decrease heart rate, stroke volume, or both, such as parasympathetic stimulation, increased or decreased levels of potassium ions, decreased calcium levels, anoxia, and acidosis, will decrease cardiac output [24], [22].
- 2) *Compliance*, which is the ratio of the change in volume to the change in the pressure applied to a vessel [25]. Arterial compliance has a direct relationship with its efficiency. There is an inverse relationship between blood pressure and compliance of blood vessels. When vascular diseases cause artery stiffening compliance decreases and the heart should work harder to push blood through the stiffened arteries, resulting in an increase in the BP [24].
- 3) *Blood volume*, or the total amount of blood in the body directly affects blood flow and pressure. If blood volume decreases due to bleeding, dehydration, vomiting, severe burns, or certain medications, blood pressure and flow also decrease. However, the body's regulatory mechanisms are efficient in controlling blood pressure, and symptoms may not appear until 10-20% of blood volume is lost. Hypovolemia can be treated with intravenous fluid replacement, but the underlying cause must also be addressed. Intravenous fluid replacement is typically part of the treatment. Hypovolemia can be treated with intravenous fluid replacement, but the underlying cause must also be addressed to restore homeostasis in these patients [24], [26].
- 4) *Blood viscosity*, is the fluids' thickness (resistance to blood flow). Blood viscosity is inversely proportional to flow and directly proportional to resistance. As a result, any factor that increases the blood viscosity will raise the

resistance and lower the flow. In contrast, factors that decrease viscosity will increase flow and lower the resistance. Blood viscosity typically does not vary over short time intervals. Plasma proteins and the formed elements are the two primary factors influencing blood viscosity. Any condition that affects the number of plasma constituents, such as red blood cells, can change viscosity [24]. Since the liver produces most plasma proteins, liver impairments or dysfunctions such as hepatitis, cirrhosis, alcohol damage and drug toxicity can also alter the viscosity and decrease the blood flow. [27].

- 5) *Blood vessel length and diameter.* The vessels' resistance and lengths have a direct relationship. Longer vessels have more resistance and a lower flow. A higher surface area of the vessel makes it harder for blood to flow through it. Similarly, shorter vessels have a smaller resistance, resulting in a higher flow. The length of blood vessels grows with age, but they tend to stabilize and remain constant in length during adulthood under normal physiological conditions [22], [24]. The diameter of blood vessels differs depending on their type and can change throughout the day in response to chemical and neural signals. Unlike vessel length, vessel diameter is inversely related to resistance. Intuitively, a vessel with a larger diameter allows blood to flow with less friction and resistance (even with the same blood volume), because the blood has less contact with the vessel walls. [24], [28].

C. Blood pressure norms

In 2018, the American Heart Association (AHA) journal published a guideline for the prevention, detection, evaluation, and management of BP. Table I lists the BP ranges of adults in five categories. BP values of children and adolescents are generally lower than adults, and they gradually rise with age [29]. Hypertension (abnormally high blood pressure), is characterized by a continuous elevation of blood pressure values above the normal range. On the other hand, hypotension (abnormally low BP) occurs when BP values are below normal ranges. Hypotension can happen due to a sudden blood loss or a decrease in blood volume, and hypertension is linked to an increased risk of various forms of CVDs [30]:

TABLE I: Blood pressure norms based on the health status of an adult [31], [32]

BP category	SBP(mmHg)		DBP(mmHg)
Low BP (Hypotension)	< 90	or	<60
Normal BP	90–120	and	60–80
Elevated	120–129	and	<80
High BP (Hypertension) Stage1	130–139	or	80–89
High BP (Hypertension) Stage2	≥140	or	≥90

III. BLOOD PRESSURE MEASUREMENT METHODS

BP readings are also impacted by the measurement technology, measurement setup, patient conditions and time. We will study these factors in the sequel.

A. Invasive blood pressure measurement

In this type of measurement, a catheter (a thin tube utilized to administer drugs, fluids, or gases into or out of a patient's body) is inserted into a vessel and measures the arterial BP using a pressure transducer consisting of a delicate and sensitive diaphragm. The transducer's resistance varies with the slightest pressure changes, allowing for the detection of blood pressure fluctuations [8]. This technique is utilized to record and monitor changes in blood pressure [33].

In modern healthcare facilities, disposable pressure transducers are commonly utilized for precise and continuous measurement of blood pressure in specialized units, such as cardiac catheterization labs, intensive care units (ICUs), and operating rooms. Although pressure transducers can measure intracranial and intra-abdominal pressures, they are most frequently used for invasive monitoring of arterial and venous blood pressure. Invasive methods of monitoring blood pressure can be generally classified into two categories [34]:

- **Intravascular:** where the pressure sensor is inserted into the vessel at the tip of the catheter;
- **Extra vascular:** where the pressure sensor is located outside the vessel and along the catheter's end

B. Noninvasive blood pressure measurement

Noninvasive blood pressure measurement techniques determine the BP without any physical injury to the body. This technique is classified into two groups: cuff-based and cuff-less methods. Cuff-less methods are mainly used for research and are commonly not common in clinical studies. Therefore, the scope of the current survey is on cuff-based methods.

All commercially available cuff-based blood pressure measurement technologies consist of a manometer (digital or analog), a pressure pump (manual or automatic), and a cuff. The basic principle of these devices is to apply sufficient pressure to the extremities (arm, wrist or leg) to temporarily block the blood flow through the artery. The cuff is then slowly deflated and the pressure is reduced until the blood begins to flow through the artery. At this point, the pressure in the cuff is equal to the systolic blood pressure (SBP) (Stage 3 in Fig. 2), or the peak of the BP. Since the BP oscillates through the cardiac cycle, it repeatedly falls below the external pressure, which results in repeated obstruction of blood flow (which can be heard through a stethoscope or sensed via a measurement device). The cuff pressure is then further reduced until blood flows through the artery with no obstruction, where the pressure in the cuff is equal to the diastolic blood pressure (DBP) (Stage 4, see Fig. 2).

There are various methods to identify the moments when the cuff pressure is equal to SBP and DBP. The main difference between these methods lies in their ability to detect the external-internal pressure balance points accurately [18]. These methods are:

1) *Auscultatory:* This method dates back to the late 18th century and remains the gold standard for validating novel BP measurement methods [35]. It is based on Korotkoff sounds, which are produced by the turbulent flow of blood through the compressed artery as the cuff pressure is slowly released,

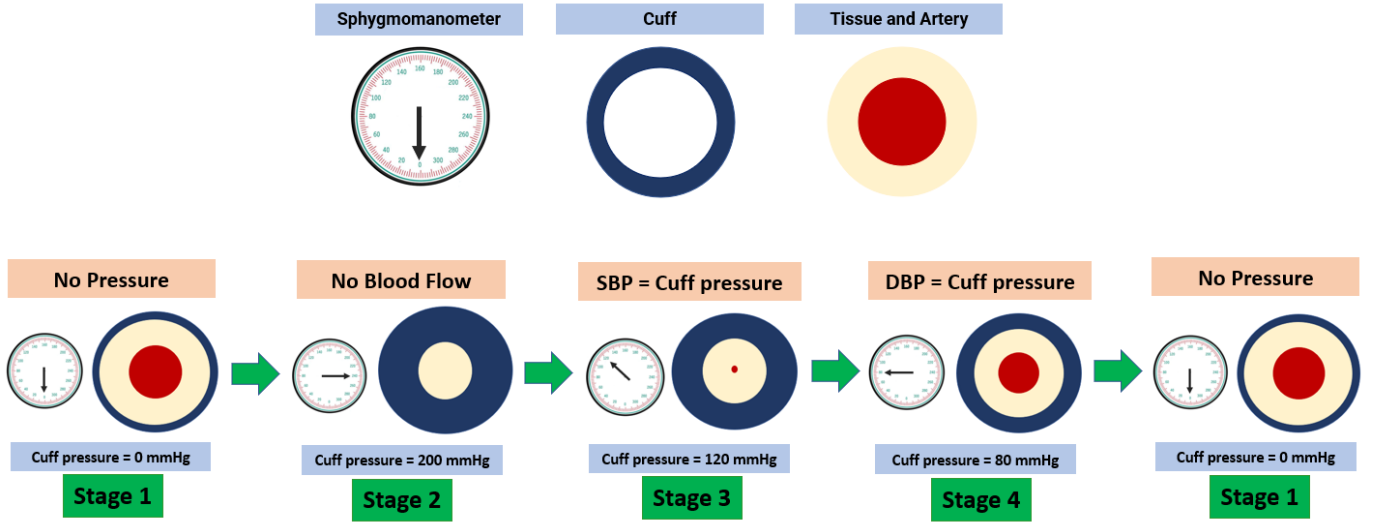


Fig. 2: Blood pressure measurement using cuff-based devices has different stages. In the basic state, the cuff's pressure is zero (Stage 1). Then, due to cuff inflation, the cuff's pressure is higher than the blood pressure. So, there is no blood flow (Stage 2). After that, the cuff deflation is started, and cuff pressure is slowly reduced until there is very little blood flow. The cuff's pressure at this moment is equal to systolic blood pressure (Stage 3). The cuff pressure decrease until blood moves very easily in the artery. The cuff's pressure at the moment is equal to diastolic blood pressure (Stage 4). Finally, the cuff pressure decreasing continues to come back to stage 1.

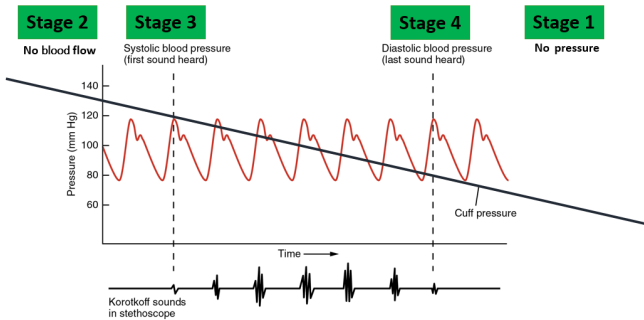


Fig. 3: Auscultatory method measures blood pressure based on Korotkoff sounds. This figure shows different stages of measuring blood pressure (Adopted from [24], licensee (CC-BY-3.0))

the artery begins to open and its pressure exceeds the cuff pressure. The pressure that the manometer displays when the first Korotkoff sound is heard corresponds to the systolic BP. At the cuff pressure reduces, the blood flows turbulently in the artery, and the sound continues until the pressure of the cuff reaches the lowest arterial pressure. At this moment, the Korotkoff sound disappears, and the corresponding manometer pressure is the diastolic BP, as shown in Fig. 3 [35], [36].

Initially, BP was measured using mercury sphygmomanometers, but the toxicity of mercury led to the adoption of aneroid sphygmomanometers, which uses a mechanical pressure gauge that is calibrated to display the pressure readings. The precision of the aneroid sphygmomanometer depends on the operator's proficiency in auscultation and use of a stethoscope, and visual acuity [35]. More recently, hy-

brid sphygmomanometers automate the detection of Korotkoff sounds and the display of the SBP, DSP and pulse rate on digital monitors [37]. To note, Aneroid sphygmomanometers' accuracy has notable variations across manufacturers. Over the past decade, surveys have been conducted to assess the accuracy of these devices. The results demonstrate that the BP readings from various manufacturers have significant deviations ranging from 1 to 44 %. Additionally, using a small gauge to read the pressure is another potential source of bias in these devices [35]. Therefore, mercury sphygmomanometers still remain popular in clinical settings.

2) *Oscillometric*: This method is currently the most popular technology for automated BP measurement devices [6]. Using a pressure sensor, it measures the pulsatile BP in the artery during cuff inflation and deflation [5]. In this technology, the transducer detects the small variations in arterial pressure oscillations or the intra-cuff pressure, produced by the changes in pulse volume due to the heartbeats [6]. The oscillations begin when the cuff pressure exceeds the systolic BP and continues until it is lower than the diastolic BP. A microcontroller is used to control the inflating process, reading the analog output signal of the pressure sensor and its digitization. The micro-variations of the sensed pressure is filtered and pre-processed to obtain the mean arterial pressure as defined in (1) [6]. Due to the indirect nature of this approach, the measured pressure value requires calibration to be mapped to the actual systolic and diastolic BPs. The microcontroller displays the measured BPs on a local screen [35].

Some of the advantages of the oscillometric method include [35], [6]: 1) ease of use for patients (placement and removal of the cuff); 2) ease of calibration (commonly via a button on the device); 3) portability; 4) applicable with minimal

training. The negative aspect of this method is that commercial oscillometric devices use different (and commonly proprietary) algorithms to estimate BP from the measurements [38]. This results in an intrinsic source of bias in BP measurement from different manufacturers.

3) *Ultrasound*: This technique is based on the Doppler effect [6]. Similar to the previous methods, cuff inflation blocks the blood flow in the artery. Then, as the cuff deflates, the arterial wall starts to move at the systolic BP, and produces a Doppler phase shift in the reflected ultrasound. As the arterial motion decreases and reaches its endpoint, the cuff pressure at that moment is considered as the diastolic BP [35]. The detection of the onset and offset of arterial wall motions is performed by processing the Doppler reflection by a local (digital) processor.

IV. CUFF-BASED BLOOD PRESSURE MEASUREMENT TECHNOLOGIES

As with all medical equipment, BP measurement devices must meet regulatory requirements and standards. In this section, the essential BP measurement and validation standards of commercial cuff-based BP monitors are reviewed.

A. BP measurement device standards

There are different standards for validating BP measurement devices. In 1987, the USA Association Advancement of Medical Instrumentation (AAMI) published the first standard for non-invasive BP medical devices. In 1990, the British Hypertension Society (BHS) set another clinical protocol for validating these devices, which includes many of the AAMI standards [39], [40]. These parallel standards continued until 2018 when the AAMI, the European Society of Hypertension (ECH) and the International Organization for Standardization (IOS) published a universal protocol named “single universal standard”, also referred by the ISO 81060-2:2018/Amd 1:2020 on “non-invasive sphygmomanometers”, [6]. The unified standard facilitated the validation and comparison of measurements made by BP devices manufactured globally.

As part of this standard, manufacturers are required to collect a database of at least 85 individuals and a minimum of three times per individual. Therefore, at least 255 records are required to validate BP devices [18]. Moreover, the mean absolute error between the recorded BP values and the reference technology, and the standard deviation of the multiple measurements should be less than 5 and 8 mmHg, respectively. The standard also classifies the performance of BP measurement devices based on their cumulative absolute error percentage into three groups of less than 5, 10, and 15 mmHg. Devices will pass the certification test if at least 85 percent of the reported results based on the noted criteria are less than 10 mmHg [6]. The reference BP measurement technology is the invasive BP measurement techniques (Section III-A), but it is acceptable to compare the BP results with any non-invasive measurement method with a maximum error of 1 mmHg.[6].

B. Commercial cuff-based BP measurement devices

Commercial BP devices may be categorized into three groups: ambulatory BP monitors (ABPM), office BP (OBP) monitors, and home BP monitors (HBPM).

The ABPM or BP Holter is a portable monitor that is carried by individuals with hypertension (or those who are at a higher risk of developing hypertension) for a period of 24 or 48 hours, while engaging in their regular daily activities and during sleep. Based on the physician’s required settings, the device measures the patient’s BP at specific time intervals, e.g. 15 or 30 minutes. After a required period, the patient returns to the clinical center, the device is taken off the patient, and the BP data is transferred to the computer/cloud and analyzed by software [18]. ABPM is most commonly used for detecting non-dipping BP patterns [41].

OBP is the most common type of BP measurement devices for clinical use. Its accuracy is very critical (especially in emergency and surgical units), where physicians make essential real-time decisions from the BP and other vital signs values. In these situations, the physician may not have adequate time to repeat BP measurement (as advised by BP reading standards). These devices have two types. These BP devices are either integrated into bedside monitors or are used as discrete devices similar to the HBPM type.

C. Standard blood pressure measurement conditions

Several guidelines have been published to improve the accuracy of BP measurement devices by standardizing BP acquisition procedures. Although there are different recommendations in different countries and organizations, they typically address the same fundamental issues [42]. Fig. 4 illustrates the basic principles of BP measurement [43]. The following are some of the common items for BP measurement guidelines:

- To maintain a stable BP measurement environment, it is recommended to refrain from opening and closing windows and doors. [35].
- The temperature and relative humidity of the BP measurement environment should be in the range of 15–25 °C and 20–85 %, respectively [35].
- BP should be measured in a quiet environment [44], [43].
- The patient should not smoke, eat or drink at least 30 minutes before measuring [43].
- The patient should have adequate rest time before the measurement to stabilize the BP.
- The patient should not speak and should remain quiet during the measurement [43].
- The patient should sit on a chair with back and arm supports and without crossing legs [44].
- The patient’s arm should be placed and remain at the same level as the heart throughout BP measurement [35].
- An appropriate cuff should be used for measuring according to AHA guidelines (Table II) [35].
- The antecubital fossa (the area between the anatomical arm and the forearm) should be 2-3 cm above the lower end of the cuff [45].
- During the measuring, the patient’s leg should remain flat on the floor [43].

TABLE II: AHA recommendation for the appropriate cuff size per patient [35]

Cuff	Arm circumference (cm)	Bladder width (cm)	Bladder length (cm)
Newborn	< 6	3	6
Infant	6-15	5	15
Child	16-21	8	21
Small adult	22-26	10	24
Adult	27-34	13	30
Large adult	35-52	20	42
Adult thigh	45-52	20	42

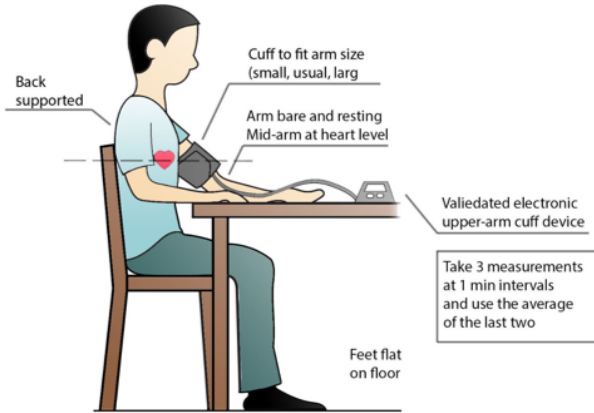
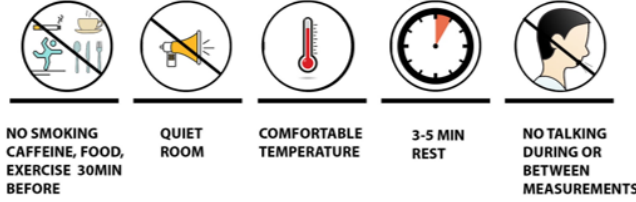


Fig. 4: The basic principles and important standards of blood pressure measurement (Adapted from [43])

- Measuring blood pressure should be done using direct contact of the cuff with the upper part of the arm (not over sleeves) [44].
- It is recommended to take three BP measurements with one-minute intervals in-between. The average of the results should be reported as the BP values [43], [44].

V. POTENTIAL SOURCES OF BIAS IN BLOOD PRESSURE TECHNOLOGIES

Patient positions or acquisition circumstances that do not meet the measurement guidelines may potentially result in BP measurement biases (over or under-estimation) and misdiagnosis [42], [46], [38]. We will study the potential sources of biases under three categories [47], [38].

A. Biases related to blood pressure measurement devices

The BP measurement device is the first source of measurement bias. BP devices comprise of the main measurement unit and the consumable parts, as detailed below.

1) *Main blood pressure measurement unit:* Biases related to the main BP measurement unit are known as systematic errors. Medical devices require maintenance and regular calibration to identify and reduce measurement uncertainties to an acceptable level. Medical instruments comprise numerous electro-mechanical elements that undergo natural aging and wearing and are impacted by microscopic airborne contaminants that accumulate on their sensitive electronic elements and sensors. These effects change the electro-mechanical characteristics of the devices (even if they are not used), and result in a gradual drift from their nominal operating point. At a system's level, the deviations of the device elements contribute to measurement biases. It should be highlighted that the effect of device aging is not identical to the failure of the elements or the device. Therefore, Hence, even though a blood pressure device may appear new or be fully functional, it may deviate from the calibration point.

Therefore, the regular calibration of medical devices is an essential requirement that should not be compromised. To note, systematic errors such as the changes in the cuff deflation rate [48], are not mitigated by averaging, as they tend to drift the reported values by a constant bias (unknown to the user) [49]. The identification and correction of systematic errors is performed by reference instruments that have been well-maintained and calibrated by medical instrumentation experts.

Another source of systematic error is the software/algorithm used for BP calculation from the pressure sensor measurements.

The algorithm that estimates diastolic and systolic pressures and the electronic pressure sensing system's lack of calibration can result in systemic errors [49], [50]. For example, in automatic BP measurement devices, the rate of cuff inflation and deflation is significant because the isometric exercise involved in inflating the cuff causes a temporary elevation of about ten mmHg. Although this only takes about 20 seconds, if the cuff is deflated too quickly, the pressure may not have returned to baseline, resulting in a falsely high systolic pressure [38]. We can also mention sensor accuracy, and software logic [35]. Also, the cuff's deflation or bleed rate is assumed to be a regular pulse when the algorithm calculates the systolic and diastolic pressures [35].

WHO publishes many guidelines for standard practice to ensure that healthcare providers focus on this issue because medical calibration is considered a part of quality healthcare [51]. The process of calibrating medical equipment is different for each one. Most of the time, the manufacturer provides a built-in system for calibrating the processes. The manufacturers also suggest a specific time for calibration, but the user can change its frequency based on the time of using the equipment. The manufacturers set the tolerance limit for each device. The testing device can be utilized further if the calibration results fall within the tolerance limit. However, the device cannot be used for any process if the calibration fails. Devices that fail the calibration call for corrective action.

2) *Consumables of blood pressure measurement devices:*

A list of the components required for measurement should be available to guarantee the devices' usability. They may include batteries, rubber tubing, hoses, fittings, and various cuff sizes [6]. Each can be important if they are not in a convenient condition. For instance, weak batteries are one of the most common causes of bias. The cuff needs sufficient power to inflate and stop the blood flow. Consequently, when the person whose BP is being measured has a higher systolic pressure, the cuff requires more power. If the batteries are weak, they cannot provide enough power to inflate the cuff, which causes systemic errors. In this situation, an error code is displayed on the device's screen. So it is better to replace the device's batteries to avoid measuring errors. Also, the tube should not have.

B. *Subject-specific biases*

BP values can be significantly changed due to various subject-related factors [52]. In the following, we will investigate some of the most important ones.

1) *Demographic features:* The "demographic features" term is very general. In current work, it means every character is linked to a person, and the critical issue is that they are not related to time or don't change at the moment, such as age, sex, race, weight, and height. They affect BP values and change them. The first and most apparent demographic feature is sex. Studies have illustrated that males have higher BP values in most cases than females for physiological reasons. According to medical referrers, the hormonal compound of male and female bodies is the reason for this difference [53]. Table III shows the results of studies that compare BP values based on gender directly or indirectly. Also, Fig. 5 shows them in a graphical view. Each ellipse represents the results of an individual study. The center of each ellipse is (mean SBP, mean DBP). One-half of the length of the horizontal and vertical axes is equal to the standard deviation of SBP and DBP, respectively. Furthermore, it demonstrates heat maps of SBP and DBP distribution due to modeling BP values distribution based on the Gaussian function.

Age is another demographic feature. When people get older, arterial stiffness increases, arterial compliance reduces, and pulse pressure rises [45]. For example, some older people have systolic hypertension, a condition with increased systolic pressure and no increased diastolic pressure. This phenomenon has been attributed to a decrease in the arteries' distensibility. In extreme cases, this may reduce the cuff's ability to compress the artery and result in falsely high readings. It is known as "Pseudohypertension" [45]. Carrico et al. [72] have investigated the relationship between sex and age in a group that consists of 965 men and 1114 women (in the Fels Longitudinal Study). Their research results demonstrate that overall BP values increase with age. However, it decreases in old age and after about 70 years old. Also, in most age groups, males' BP is higher than females'. But, their BP is the same until their teenage years. After about 70 years old, females' SBP values are more than males' ones and their DBPs are about equal.

Height and weight are two other features that are really important factors in BP values. SBP and DBP are significantly lower and higher in taller people [70]. Also, we can refer to the body mass index (BMI) as a ratio of them. It is equal to weight divided by height squared (kg/m^2) [73], [74]. BMI is positively correlated with BP [75]. Table IV and Fig. 6 demonstrate the results of studies that have reported BP values based on BMI.

On the other hand, different studies have examined the relationship between race and BP values [94]. According to their results, specific diseases are more common in individual ethnic groups [95]. For instance, Staessen et al. [96] have discovered that Asian populations have a higher rate of non-dipping than European populations. Race significantly impacts hypertension prevalence, and control rates [95]. People of African American descent have higher rates of hypertension, cardiovascular and cerebrovascular morbidity, and mortality compared to European descent [97]. The black population seems more susceptible to hypertension [95]. Table V summarizes studies that have compared BP values based on race.

2) *Specific patient populations:* The biological rhythms inherent to the disease process and their potential clinical implications are typically ignored or given little credit in treating hypertensive patients [41]. During measuring BP values, it is essential to consider the specific condition of patients and their underlying disease because they influence BP values directly or indirectly. For example, studies demonstrate in healthy people during the 24 hours, BP values fluctuate, rising during the day and falling at night. Most people have a low blood pressure pattern in their nighttime reading, which is 10-20% lower than their daytime reading. A non-dipping BP pattern is one in which a person's BP falls less than 10 percent at night. [98]. Studies show that approximately 25 percent of hypertensive people with unidentifiable causes have non-dipping BP.

Also, the phenomenon known as the "white-coat effect" occurs when a patient's BP changes due to a response to the medical environment and the physician's presence [38]. In most cases, this change will increase systolic and diastolic BP rather than the usual condition [46]. Table VI summarizes the results of studies that compare BP values regarding the environment of measuring BP, such as the home or office.

Almost ten percent of pregnant women have high BP, which can hurt both the fetus and the mother [45]. Perinatal with gestational diabetes or Preeclampsia are the high-risk groups [42]. Pregnant women's altered hemodynamics are thought to cause differences in BP readings compared to the not pregnant population. While there are a lot of automated BP devices, only a few have been proven accurate for pregnant women with or without hypertensive disorders [7].

It is necessary to keep DBP and SBP below 80 mmHg and 130 mmHg, respectively, to protect the kidneys from damage due to high BP in the diabetics' population and people with kidney disease [42].

Obesity has a direct relationship with high BP in both children and adult populations. Table VII illustrates the results of studies that investigate the effect of obesity on BP values in the children population. The SBP and DBP of obese children

TABLE III: The results of studies that have reported the blood pressure values based on sex.

Ref.	Total N	Male			Female		
		N	SBP	DBP	N	SBP	DBP
[54]	20	10	126 ± 8	73 ± 5	10	122 ± 5	73 ± 5
[54]	26	13	117 ± 5	65 ± 7	13	103 ± 6	62 ± 8
[55]	37	22	121.2 ± 9.7	73.7 ± 8.5	15	117.4 ± 13.9	74.8 ± 12.2
[56]	39	24	122.9 ± 13.2	82.6 ± 10.1	15	110.5 ± 8.8	74.5 ± 7.3
[57]	40	20	128.2 ± 12.3	83.3 ± 5.8	20	117 ± 14.4	75.5 ± 12.3
[58]	45	23	119 ± 9.5	76 ± 4.7	22	111 ± 4.6	72 ± 4.6
[59]	55	26	129.10 ± 9.12	64.21 ± 8.31	29	107.95 ± 9.80	61.70 ± 6.67
[60]	92	55	105.6 ± 10.3	58.5 ± 9.3	37	103.4 ± 11.8	56.9 ± 8.9
[60]	107	42	114.3 ± 12.2	62.5 ± 13.3	65	100.3 ± 10.0	63.6 ± 10.9
[61]	122	52	137 ± 20	86 ± 12	70	145 ± 26	87 ± 15
[62]	141	117	128.8 ± 10.4	81.3 ± 5.3	24	126 ± 11.8	77.6 ± 7.4
[63]	312	142	116.3 ± 9.9	66.4 ± 7.1	170	112.25 ± 8.3	66.5 ± 6.8
[63]	351	184	113.7 ± 9.0	64.5 ± 6.6	167	109.8 ± 7.5	64.1 ± 5.9
[64]	806	237	120.6 ± 12.9	77.9 ± 8.7	569	112.7 ± 12.3	71.7 ± 8.4
[65]	1030	614	123.3 ± 12.3	77.3 ± 8.2	416	117.1 ± 10.6	73.9 ± 7.1
[66]	1298	638	127.4 ± 14	77.7 ± 10.5	660	124.4 ± 15.7	74.5 ± 9.7
[67]	1378	664	122 ± 10.5	72 ± 9.4	714	113 ± 9.9	68.2 ± 8.6
[67]	1534	767	132 ± 16.4	83.1 ± 9.3	767	126 ± 16.1	78.9 ± 9.2
[68]	2105	945	132 ± 18	79 ± 11	1160	122 ± 18	75 ± 10
[69]	2442	1577	129.7 ± 19.2	80.9 ± 10.6	865	123.2 ± 20.9	76.5 ± 10.3
[70]	2849	1505	124.6 ± 15.5	73.8 ± 15.5	1344	120.0 ± 18.3	71.2 ± 14.6
[70]	3654	1915	120.0 ± 21.8	70.5 ± 17.5	1739	115.0 ± 20.8	68.2 ± 16.6
[70]	6485	3379	121.7 ± 23.2	72.9 ± 17.4	3106	117.8 ± 22.2	70.4 ± 16.7
[71]	33599	19704	138.7 ± 18.4	81.3 ± 11.5	13895	132.1 ± 19.3	77.4 ± 11.6

increased by an average of 0.56 and 0.54 mmHg for each 1-unit increase in BMI. [73].

3) *Eating, drinking or smoking before blood pressure measurement*: Generally, our eating, drinking, and smoking habits affect our BP values. Studies show that food consumption can influence the amount of BP and decrease its actual amount over short and long periods. All national and international guidelines recommend making lifestyle and dietary changes as the first step in managing hypertension. Regarding nutritional factors affecting hypertension, most current research focuses on reducing salt intake to control BP. To improve this process, a group of physicians suggests increasing potassium-rich foods like nuts, fruits, and vegetables [101]. On the other hand, food consumption can show its effect quickly and early. For example, a group of researchers found significant decreases in SBP and DBP 180 minutes after the mixed meal was consumed but no significant effect at 60 minutes. The results of most studies about the impact of drinking alcohol have demonstrated that BP values grow in association with the dose of alcohol and the BMI of the consumer. Also, using caffeine, nicotine, or smoking has a nearly short-term effect related to its dose [46]. Table VIII shows the results of studies on the effect of eating, drinking, or smoking on BP values.

4) *Circadian clock*: According to many studies, the circadian clock impacts essential CVD risk factors like heart rate and BP. A circadian clock, composed of two separate components, drives human circadian rhythmicity: the central clock, which is in the hypothalamic suprachiasmatic nucleus (SCN), and the peripheral clock, which is in almost all body tissues and organ systems. In addition, depending on the time of day, circadian rhythmicity can be entrained or aligned by environmental factors like physical exercise that stresses skeletal muscle [108]. In the early morning hours, the

maximum BP values can be measured. Then, its levels remain nearly stable until the early evening. After that, they decline slowly and reach the lowest values at midnight. Boivin et al. [109] have studied the changes in BP values in the morning before eating breakfast and in the evening after eating dinner, among 52 hypertensive-controlled patients. In every measure in the morning and evening, BP was recorded six times. Half of them were before rest and another half were after resting. This process took nine minutes. Also, there was a one-minute time interval between measurements and the rest time was 5 minutes. The results of this study demonstrate the clear BP difference between morning and evening values. Based on the third measure in the morning and evening, the difference is about 5 and 8 mmHg for DBP and SBP, respectively.

Various psychological and physical activities cause BP to fluctuate between high values during work hours and low at home. Although several other neurohormonal systems have been demonstrated to follow a circadian rhythm with a peak in the morning, the sympathetic nervous system appears to be the primary determinant of these BP circadian variations. Also, this principle can be inverse due to the job of people such as shift workers [41]. Table IX compares the results of studies investigating the circadian clock's effect on BP values.

C. Biases related to the acquisition session

As mentioned earlier, there are detailed guidelines for measuring blood pressure, failure to follow them will cause errors in the correct reading of pressure values. In the following, we will examine the impact of many factors that people involved in measuring other people's BP should consider.

1) *Ambient temperature*: Studies show SBP and DBP fluctuate seasonally. The highest values are observed in winter, and the lowest values in summer. Home and ambulatory BP, as well

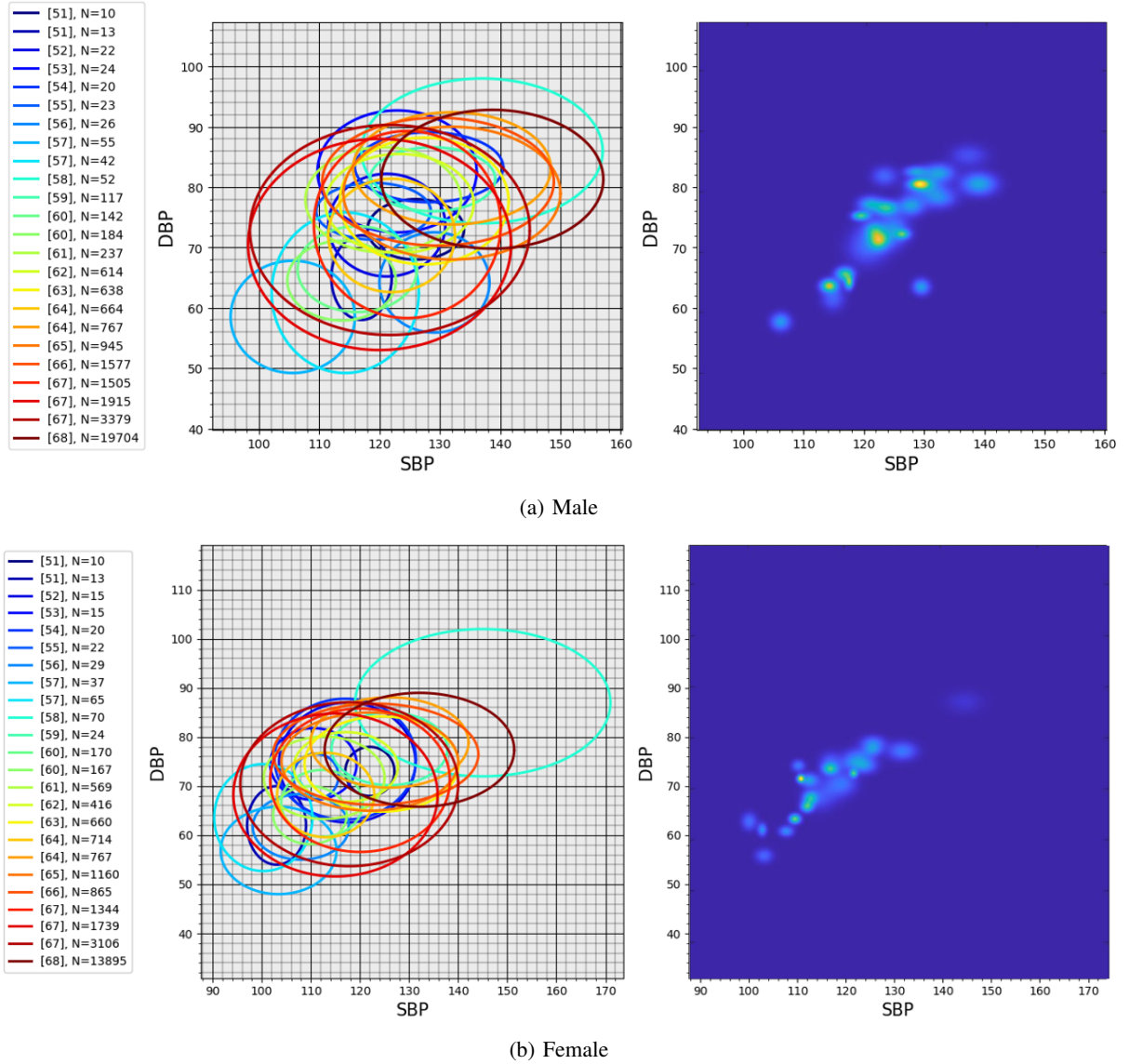


Fig. 5: The results of studies comparing blood pressure values based on sex (Male vs Female). Each ellipse represents the results of an individual study. The center of each ellipse is (mean SBP, mean DBP). Each ellipse's horizontal and vertical radii are the standard deviations of the reported SBP and DBP, respectively. Also, it shows heat maps of blood pressure distribution.

as clinic BP, exhibit this seasonal variation. Although conclusive evidence does not exist for a direct relationship between BP and ambient temperature, these seasonal variations point to a correlation [110]. The results of Yang, et al. research [111] demonstrates the fluctuation of BP values in various months. In this study, the BP values of 23040 people with prior CVD were gathered between 2004 and 2008 in China. They have reported the results regardless of the year. In other words, the mean of monthly BP values represents the mean of BP values for all participants in a specific month. The maximum and minimum BP values have been reported in the winter (Dec/Jan/Feb) and summer (Aug/Jul). Table X illustrates the results of studies that compare BP values based on the environment temperature. Short-term effects on BP values are caused by temperature. To maintain stable BP levels and reduce the risk of BP-related

diseases, timely protective measures during cold weather are advantageous [83].

2) *Cuff position*: The brachial artery is the most common place to measure BP [45]. Although wrist and finger pressure monitors have gained popularity, it is essential to know that SBP and DBP values differ significantly throughout the arterial tree [38]. Fig. 7 is a simple schematic diagram demonstrating the impact of different body points on BP values when blood moves through various arteries in an upright position. Table XI illustrates the results of studies comparing BP values at various human body points.

3) *Body position*: It is common knowledge that body positions can influence BP values. According to guidelines, the sitting position with the back supported by the back of the chair is defined to measure BP [47]. Therefore, this factor should be considered in reporting BP values. Many groups of

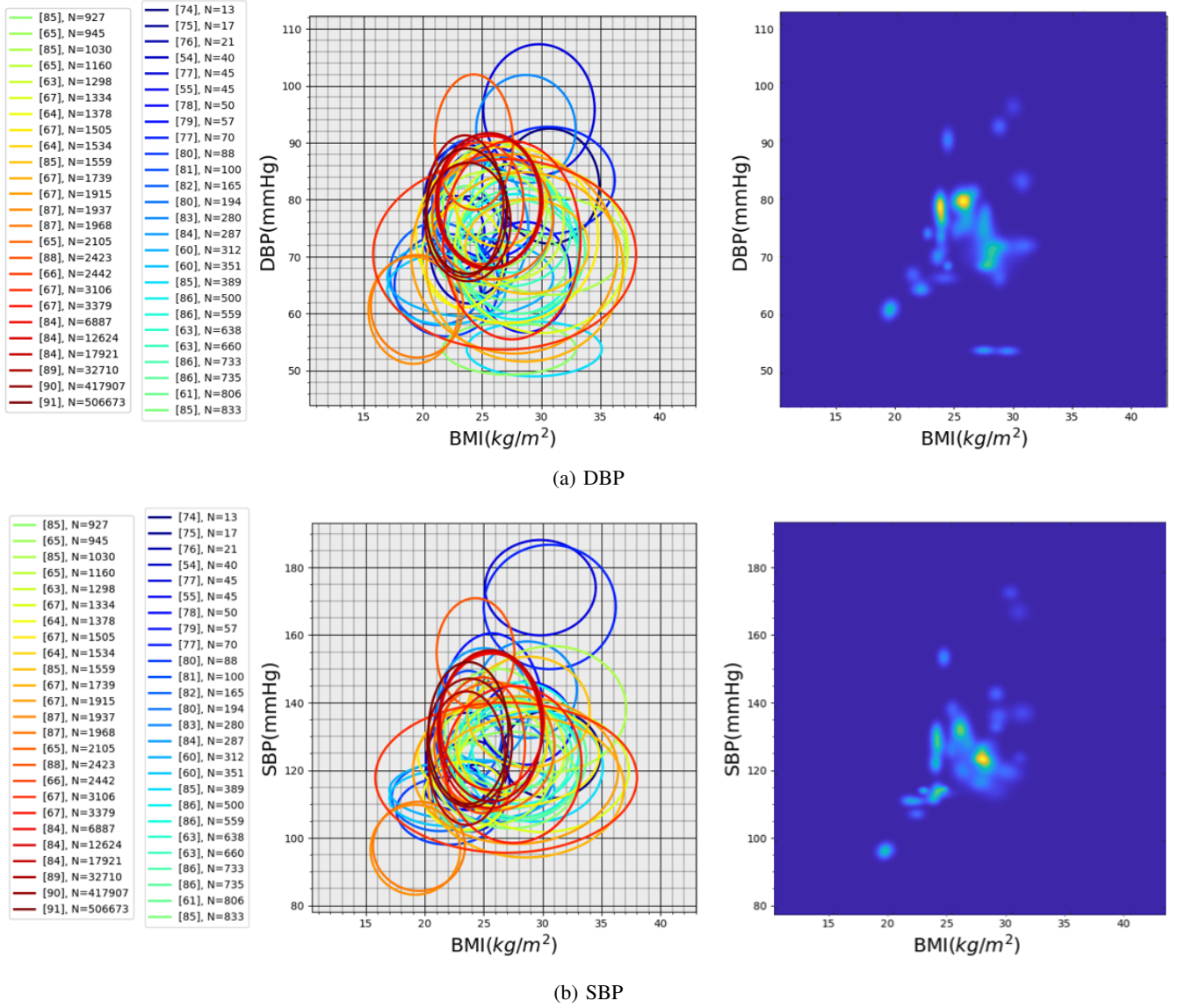


Fig. 6: The results of studies that compare the BP values based on BMI. Each ellipse represents the results of an individual study. The center of each ellipse is (mean BMI, mean BP). Each ellipse's horizontal and vertical radii are the standard deviations of the reported blood pressure and BMI, respectively. Also, it shows heat maps of blood pressure distribution

researchers have examined the effect of this issue. It seems that BP values are higher in the sitting position than supine [85], [66]. Overall, the BP cuff should be positioned at the level of the patient's right atrium, regardless of whether BP is measured in the seated or supine position [45]. Table XII shows the results of studies that compare BP values according to different positions of people during the measurement.

4) *Arm position:* The patient's arm should be placed on a table or supported by an armrest at the level of the heart. As the arm is moved from the horizontal to the vertical position, the pressure gradually rises by 5 to 6 mmHg due to changes in hydrostatic pressure. During the BP measurement, it is also critical that the patient's back be supported. For instance, the DBP of individuals who sit straight up may be up to 6.5 mmHg higher than those who sit back [38]. Table XIII demonstrates the results of studies comparing BP values according to various

arm positions.

5) *Leg position:* BP measurement guidelines emphasize that patients should keep their feet on the floor to accurately and precisely measure. Researchers have investigated this issue to determine how the leg position affects the patient's BP during measurements. Overall, BP values in crossed-leg positions are higher than in uncrossed-leg positions and sitting with feet flat [46]. Table XIV shows the results of studies that compare BP values according to various leg positions.

6) *Left or right arm:* According to the guidelines, BP in each arm should be measured at the first visit, and the arm with the highest BP should be used at subsequent visits. It is so common that the BP values in the different arms have clinically significant differences. Coarctation of the aorta or upper-extremity arterial obstruction could cause a considerable difference [45]. Table XV illustrates the results of studies

TABLE IV: The results of studies that have reported the blood pressure values based on BMI.

Ref.	N	BMI	SBP	DBP
[76]	13	30.7 ± 4.2	124.7 ± 13.0	82.4 ± 10.1
[77]	17	24.3 ± 2.4	115.4 ± 6.2	68.5 ± 5.4
[78]	21	23.9 ± 3.3	115.4 ± 13.5	71.2 ± 9.4
[57]	40	23.6 ± 3.5	122.6 ± 14.4	79.4 ± 10.3
[79]	45	29.8 ± 4.7	174.0 ± 14.1	95.8 ± 11.5
[58]	45	22.6 ± 2.6	115 ± 6.7	74 ± 6.7
[80]	50	28.62 ± 3.86	133.90 ± 12.26	66.40 ± 9.70
[81]	57	25.7 ± 4.4	135.7 ± 24.8	79.5 ± 9.7
[79]	70	30.6 ± 5.6	168.3 ± 18.4	83.4 ± 9.4
[82]	88	22 ± 4.4	108 ± 10	65 ± 9
[83]	100	23.7 ± 2.9	132.9 ± 16.5	80.0 ± 10.4
[84]	165	21.3 ± 4.1	112 ± 10	67 ± 9
[82]	194	26 ± 5	120.3 ± 15.8	76.4 ± 11.3
[85]	280	28.7 ± 4.2	143.8 ± 14.3	92.4 ± 9.5
[86]	287	25.0 ± 3.9	139.2 ± 16.9	74.6 ± 12.0
[63]	312	24.0 ± 7.0	114.1 ± 9.0	66.4 ± 6.9
[63]	351	22.0 ± 5.0	111.8 ± 8.3	64.3 ± 6.2
[87]	389	29.4 ± 5.7	121.1 ± 16.3	53.8 ± 4.8
[88]	500	27.9 ± 5.3	123 ± 17	70 ± 11
[88]	599	28.1 ± 5.1	128 ± 18	72 ± 12
[66]	638	27.5 ± 3.5	127.4 ± 14.0	77.7 ± 10.5
[66]	660	27.3 ± 5.2	124.4 ± 15.7	74.5 ± 9.7
[88]	733	28 ± 5.2	122 ± 17	69 ± 11
[88]	735	28.2 ± 5.5	124 ± 18	71 ± 11
[64]	806	23.7 ± 3.0	115.0 ± 13.0	73.5 ± 8.9
[87]	833	27.5 ± 4.7	124.3 ± 9.5	68.5 ± 6.1
[87]	927	27.3 ± 5.6	117.1 ± 14.3	53.9 ± 4.6
[68]	945	26.1 ± 4.4	132 ± 18	79 ± 11
[87]	1030	30.8 ± 6.3	138.1 ± 18.6	71.9 ± 8.6
[68]	1160	25.7 ± 5.2	122 ± 18	75 ± 10
[66]	1298	27.4 ± 4.5	125.9 ± 14.9	76.1 ± 10.2
[70]	1344	30 ± 7.3	120 ± 18.3	71.2 ± 14.6
[67]	1378	23.4 ± 3.5	112.5 ± 10.1	70.0 ± 8.9
[70]	1505	27.1 ± 7.7	124.6 ± 15.5	73.8 ± 15.5
[67]	1534	26.5 ± 3.9	129 ± 16.2	81 ± 9.2
[87]	1559	28.8 ± 5.2	137.2 ± 16.4	71.8 ± 8.3
[70]	1739	28.6 ± 8.3	115 ± 20.8	68.2 ± 16.6
[70]	1915	27.7 ± 8.7	120 ± 21.8	70.5 ± 17.5
[89]	1937	19.2 ± 3.8	96.5 ± 13.3	60.6 ± 9.4
[89]	1968	19.5 ± 3.9	97.5 ± 13.2	61.3 ± 9
[68]	2105	25.9 ± 5.1	127 ± 19	77 ± 11
[90]	2423	24.3 ± 3.3	154.7 ± 16.2	90.1 ± 11.9
[69]	2442	24.9 ± 3.6	127.4 ± 20.1	79.4 ± 10.7
[70]	3106	26.9 ± 11.1	117.8 ± 22.2	70.4 ± 16.7
[70]	3379	27.5 ± 5.8	121.7 ± 23.2	72.9 ± 17.4
[86]	6887	25.7 ± 4.4	134.3 ± 20.2	79.6 ± 11.6
[86]	12624	25.5 ± 4.4	131.9 ± 23.1	79.7 ± 11.9
[86]	17921	25.6 ± 4.4	133.1 ± 22.4	79.9 ± 11.8
[91]	32710	23.55 ± 3.25	123.57 ± 19.77	78.86 ± 12.44
[92]	417907	23.8 ± 3.6	128.1 ± 19.0	76.1 ± 10.4
[93]	506673	23.7 ± 3.4	131 ± 21	78 ± 11

investigating the effect of measuring BP on the right and left arms.

7) *Cuff size*: The cuff's size must be proportional to the arm's diameter. Utilizing a too-small cuff will cause an over-estimation of pressure, which is the most common error [38]. Also, the reported BP values are significantly reduced when the cuff size increases [46]. Choosing the right-sized cuff for measuring BP in children of different ages is challenging. The BHS recommends wearing the widest cuff to fit the arm in three sizes: 4 x 13 cm, 8 x 18 cm, and 12 x 35 cm (adult cuff) [38]. In obese patients, selecting the proper size cuff is essential to compress the brachial artery to measure BP accurately [45]. In addition, most obese patients have arms

TABLE V: The results of studies that have compared BP values based on race

Ref.	N	Race	SBP	DBP
[60]	199	Black White	105.70 ± 10.91 104.71 ± 10.92	63.16 ± 11.89 57.85 ± 9.14
[97]	245	White hypertensive Black hypertensive	145 ± 18.3 142 ± 14.9	92 ± 10.7 93 ± 10.8
[63]	663	European Americans African Americans	111.8 ± 8.3 114.1 ± 9.0	64.3 ± 6.2 66.4 ± 6.9
[70]	6503	Non-Hispanic Black Mexican American	122.4 ± 16.9 117.6 ± 30.2	72.5 ± 21.3 69.4 ± 24.1
[70]	9334	Non-Hispanic White Non-Hispanic Black	119.8 ± 32.2 122.4 ± 16.9	71.7 ± 24.1 72.5 ± 21.3
[70]	10139	Non-Hispanic White Mexican American	119.8 ± 32.2 117.6 ± 30.2	71.7 ± 24.1 69.4 ± 24.1

Mean Arterial Blood Pressure

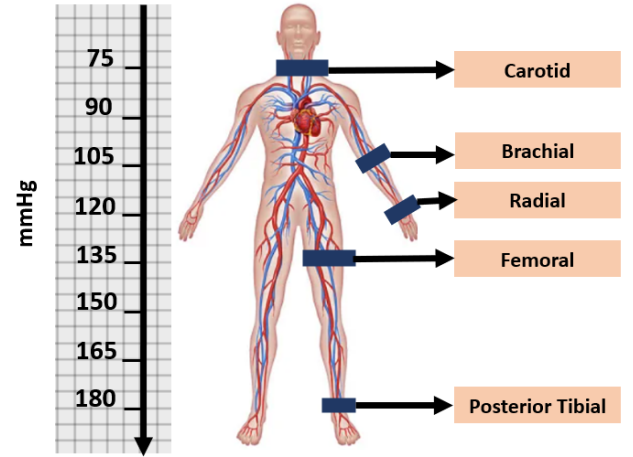


Fig. 7: Blood pressure values vary throughout the arterial tree according to distance from the heart and the kind of arteries. Also, gravity is an important factor in the blood pressure values when the person is standing. This figure shows a schematic of blood pressure values at different arteries such as carotid, brachial, radial, femoral and posterior tibial [114], [115]

that are tronco-conical, which is another problem that affects BP accuracy. Therefore, a cuff in the shape of a cone should be chosen for a more precise BP estimation [45]. Table XVI shows the results of studies that have examined the effect of cuff size on BP values.

8) *Cuff tightness*: The cuff should be pulled taut around the bare upper arm, with similar tightness at the cuff's top and bottom edges. One finger should easily fit between the top and bottom of the cuff to determine the appropriate level of tightness; it should fit two fingers [45].

9) *Rest period before measuring*: Few studies have directly examined how the rest period affects BP. According to the studies, patients who did not rest sufficiently before measurement had significantly higher SBP and DBP. It was demonstrated that resting for 10 or 16 minutes could result in a slight to moderate drop in systolic BP and a slight decline in diastolic BP. However, based on these findings, it is unclear whether extended rest periods are necessary to reverse the

TABLE VI: The results of studies that compare the blood pressure values based on the environment of measuring

Ref.	N	Home			Office		
		N	SBP	DBP	N	SBP	DBP
[99]	454	199	144 ± 18	88.6 ± 10	255	160 ± 13	99.7 ± 4
[100]	574	287	125.7 ± 8.4	72.9 ± 8.6	287	139.2 ± 16.9	74.6 ± 12.0
[90]	4846	2423	152.4 ± 3.1	89.7 ± 9.3	2423	154.7 ± 16.2	90.1 ± 11.9
[86]	13774	6887	127.3 ± 18.1	76.2 ± 9.9	6887	134.3 ± 20.2	79.6 ± 11.6
[86]	35842	17921	129.1 ± 18.6	76.9 ± 9.8	17921	133.1 ± 22.4	79.9 ± 11.8

TABLE VII: The results of studies that investigate the effect of obesity on blood pressure values in children population

Ref.	BP	Sex	Obese group		Non obese group	
			N	Mean ± SD	N	Mean ± SD
[73]	SBP	Boys	330	96 ± 13.28	331	90 ± 10.58
	SBP	Girls	253	95 ± 13.19	251	90 ± 11.49
[73]	DBP	Boys	330	60 ± 10.73	331	60 ± 9.53
	DBP	Girls	253	60 ± 11.03	251	60 ± 10
[89]	SBP	Boys	420	103.3 ± 14.8	1034	94.2 ± 11.8
	SBP	Girls	401	100.7 ± 14.1	1050	93.5 ± 11.8
[89]	DBP	Boys	420	64.4 ± 9.8	1034	59.6 ± 8.7
	DBP	Girls	401	63 ± 9.3	1050	58.8 ± 9.2
[74]	SBP	Boys	80	103 ± 13	143	98 ± 11
	SBP	Girls	28	99 ± 14	144	94 ± 11
[74]	DBP	Boys	80	57 ± 9	143	55 ± 6
	DBP	Girls	28	55 ± 11	144	50 ± 6

effects of previous physical activity [46].

10) *Number of measurements*: Studies show that the first BP reading during an office visit is frequently higher than subsequent readings for many people. A group of researchers has investigated this issue and reported it based on the average of three measurements. According to the first BP measurement values, it was estimated that 35 percent of adults in the USA had SBP and DBP in the range of 140 to 159 and 90 to 99 mmHg, respectively. While according to the average three BP measurements, SBP/DBP was less than 140/90 mmHg [45]. Table XVII demonstrates the results of studies that have examined the impact of resting for 5 minutes before measuring BP.

11) *Clothing*: According to the BP measurement guidelines, clinicians should measure BP by completely exposing the upper arm. However, measuring BP by rolling up or placing the cuff over the sleeve is common practice. Table XVIII shows the results of studies investigating the effect of the cloth on the body on BP values.

VI. THE FUTURE OF BP MONITORING

In the previous section, the potential sources of bias in cuff-based BP devices were explained entirely. In this session, we will investigate its importance using mathematical modeling of bias. After that, we will examine an example to show the effect of bias on the percentage of falsely reported cases and the classification of individuals according to the BP norm. In the last part, new ideas about the future of BP monitoring technologies will be discussed.

The problem of accurate blood measurement can be formulated as an optimal estimation problem:

$$y_k(t) = \text{BP}_k(t) + e_k(t) \quad (2)$$

Where $y_k(t)$ is the reported BP values, BP_k is the true BP values at time t for an individual subject with index k , $e_k(t)$ is some of all probable biases that happen due to items that we have described in the previous section. The BP and bias can be modeled as stochastic processes with presumed distributions. Therefore, we can assume, $\text{BP}_k(t) \sim \mathcal{N}(\mu_k, \sigma_k)$ and $e_k(t) \sim \mathcal{N}(\eta, \delta)$, independent from BP_k .

Example: BP values change due to many things during the different measurements. We consider a male whose average BP values correspond to the normal classification of Table I. In other words, the SBP and DBP distribution is $N(110, 10)$ and $N(80, 5)$, respectively. In this case, we assume just using a non-calibrated BP device is the only reason for bias. It has a fixed BP bias of $\eta = 10$ mmHg that is reported by manufacturers.

Equation 3 describes the impact of the error on the percentage of misreported BP.

$$\begin{aligned} \Pr[L \leq \text{BP} \leq L + \eta] &= \int_L^{L+\eta} \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) dx \\ &= \frac{1}{2} \left(\text{erf} \frac{L+\eta-\mu}{\sqrt{2}\sigma} - \text{erf} \frac{L-\mu}{\sqrt{2}\sigma} \right). \end{aligned} \quad (4)$$

L is the specified BP value we want to calculate the probability of its wrong reporting. We consider the L values of SBP and DBP equal to 125 and 85, respectively. Therefore, the probability of their misreporting is 24.17% and 15.73%, respectively.

A. Bias detection and blood pressure correction based on machine learning algorithms

One of the main aims of this research is to prevent bias's propagation to the following stages. In this way, we can find several studies about bias and investigating risk factors in different areas [13], [126], [44]. Despite considerable achievements, the human body is complicated and vague for scientists. BP is a small part of this great system relevant to many factors. So this issue influences the process of measuring BP values. Due to our knowledge of the complexity and the necessity to reduce bias, we should utilize artificial intelligent science and develop ML-based models to learn these hidden complications and manage biases. This process has been conducted in a few other fields, like designing a reduced-bias ML-based model according to age, sex, and race items on diagnosing arrhythmia automatically [126]. Bias detection and BP correction based on ML algorithms will affect recorded BP values using the

information that the applicant inputs, such as age, sex, and race. This process helps to personalize the BP devices for every subject that utilizes the same device. Finally, reported BP values will be closer to the actual ones. Fig. 8 demonstrates the process of using ML-based BP diagnosis algorithms. In future cuff-based BP technologies, the mentioned algorithms can be considered in their manufacturing process. Also, it seems to gather more information maybe the applicant does not aware of them, such as the temperature of the environment and noise level. We can develop special BP devices with specific in-built sensors to detect conditions such as ambient temperature and noise level during measurement [42]. Progress in materials science and fabrication methods will draw significant attention to using various sensors for healthcare issues [115].

B. Introduction new model of blood pressure chart

In the previous part, we introduced an ML-based model to personalize BP devices according to every subject. However, we still categorize people into various groups according to their BP values using the same criteria (Table I). This classification is done according to the illustration of a group of symptoms at the specific range of BP values. Therefore, an important idea can be discussed. The classification of people with various features such as gender, age, and race according to the table I is maybe incorrect. For example, overall BP values related to black people are more than white races, but we cannot claim all of them are hypertensive. In this issue, utilizing ML-based algorithms is an excellent idea to classify people based on the values of BP and their complications. We expect the ML-based model will be able to find nonlinear borders for Hypotensive, Normal, Elevated, and Hypertensive individuals and predict the probability of belonging to the mentioned groups and their risks. We anticipate the resulting ML-based models would change the current definitions between different BP stages shown in Fig. (9).

VII. DISCUSSION

One of the main reasons for the importance of bias investigation is to prevent its propagation in the following stages. For example, bias in BP technologies leads to bias in prescription drugs and treatment methods. This bias can cause irreparable damage to patients in the short or long term. Unfortunately, most people and even medical experts ignore this critical issue. In the following, we will discuss the effect of bias on the developing cuff-less BP devices and the limitations of conducting this study.

A. Impact of current BP measurement biases on cuff-less blood pressure technologies

In recent decades, numerous valuable studies have been conducted to introduce and develop new methods of measuring BP. The basis of BP measurement methods using a cuff is blocking blood flow. These methods have some limitations [36]: (1) the process of measuring BP is time-consuming, (2) they can be uncomfortable for patients due to noise generation and frequent inflation in the long term, like ABPM devices that

are utilized for recording BP during the day and at night time, (3) they can not be utilized for continuous BP measuring in heart surgical units and in some acute burns, (4) according to medical references, there should be enough time between successive BP measurements until the vessels in the tissue under the cuff can return to their original state and prevent blood vessels from collapsing due to cuff pressure. Cuff-less BP measurement methods are divided into three groups [18]: tonometry, volume clamps, and pulse wave velocity (PWV).

PWV method of measuring BP was invented by two scientists, Moens and Kortwege [33]. Based on the Moens-Kortwege (5) equation, they could define the relationship between vascular elasticity and pulse wave velocity (PWV) in the artery [36]:

$$PWV = \sqrt{\frac{Eh}{\rho D}} \quad (5)$$

h is the thickness of the vessel wall, ρ is blood density, and D is the vessel's inner diameter. In this equation, E is Young's modulus of elasticity, which indicates the elasticity of the vessel wall. Geddes defined E by the below equation [36]:

$$E = E_0 e^{\alpha(BP)} \quad (6)$$

E_0 is the modulus of elasticity at a pressure of 0 mmHg, α is a constant related to the vessel and in ranges of 0.016 to 0.018 mmHg⁻¹, and e is the Neper number. After combining equation (5) and (6) and doing some algebraic operations, equation (7) is obtained, which describes the relationship between BP and PWV as follows:

$$BP = \frac{1}{\alpha} (2 \ln(PWV) + \ln \frac{\rho D}{h E_0}) \quad (7)$$

Several methods are used to measure PWV. Pulse transit time (PTT) is the most well-known indirect method of calculating BP [3]. The relationship between PTT and PWV is defined as follows [36]:

$$PWV = \frac{d}{PTT} \quad (8)$$

d is the distance between the heart and a specific place where the blood flows, and PTT is the time it takes for the blood pulse to pass d distance. The calculation of PTT is done using different sensors and bio-signals [127]. In the following, they are listed:

- Photoplethysmography (PPG) signal and the output signal of the Hall sensor [128]
- PPG signal and modulated magnetic signature of blood signal [129]
- PPG signal and Ballistocardiography signal [130]
- PPG signal and Impedance plethysmography signal [131]
- PPG signal and ECG signal [132]
- Two PPG signals
- A PPG signal [133]

Difficulties in calculating d parameter lead we cannot directly calculate PWV value and, in the following, the BP value

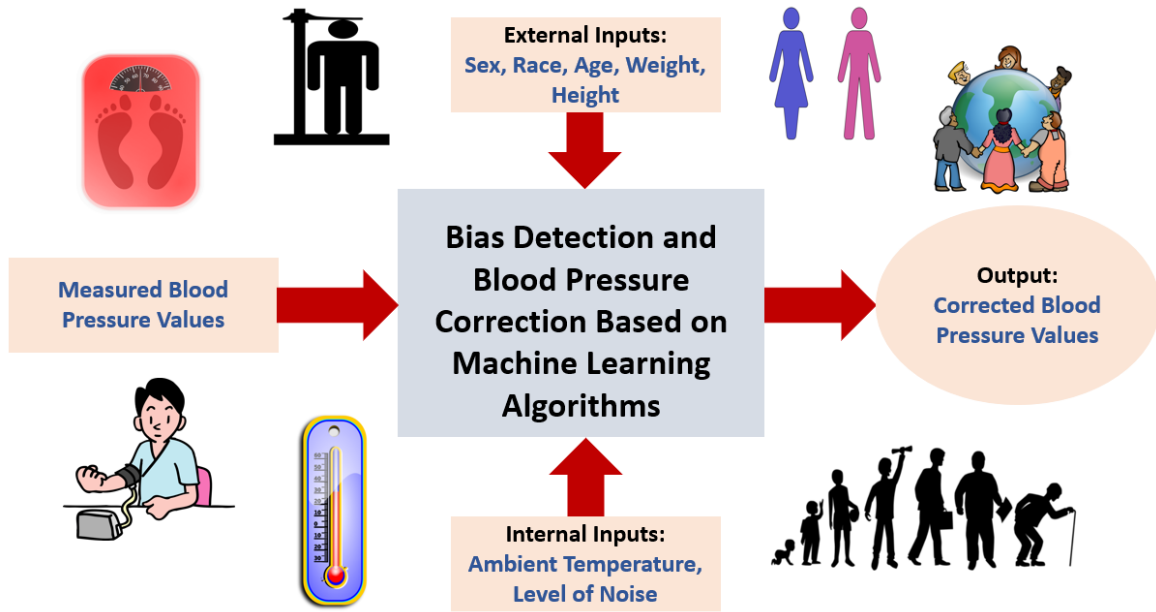


Fig. 8: The proposed idea of using MI-based algorithms in the new generation of cuff-based blood pressure measurement devices to detect bias and correct blood pressure values.

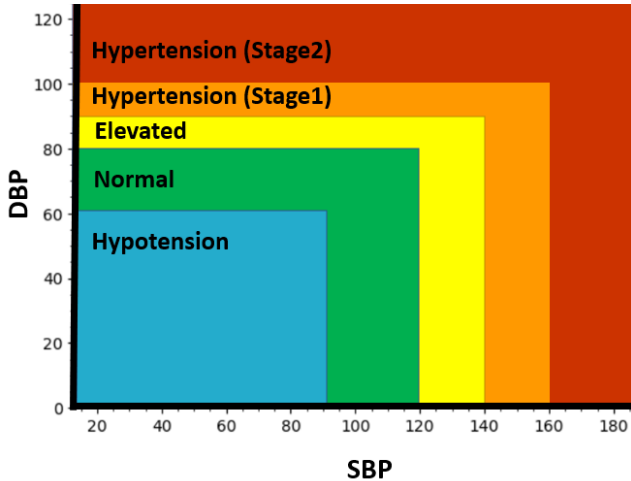


Fig. 9: The current BP classification standards depict sharp boundaries between different BP stages. ML-based BP classification is anticipated to change these standards to statistical tests involving the BP, patient's demographics, and comorbidities.

of (7). Cuff-less BP monitoring devices should use artificial intelligence algorithms to learn crucial and complex features of the cardiovascular system [8], [5]. In recent years, this issue has inspired researchers to examine how to extract the best features from the signals, such as PTT, to model the cardiovascular system and monitor BP. However, most current studies are still in the prototype stages and must overcome various obstacles to meet medical standards [5].

In developing cuff-less methods, scientists usually utilize the database related to cuff-based BP values to train the ML-based models. As a result, when we do not consider all the

conditions affecting the models, they will be trained with the wrong BP database. This bias influences model performance. Therefore, the final error related to the model's output will be the sum of the error due to bad performance in the training stages, such as many other developed ML-based models, and the bias related to cuff-less BP devices. We can predict whether the estimated BP will be closer or further away from the actual values. Consequently, this leads to an increase in the standard deviation of the difference between the actual and estimated BP values.

B. Limitations

In subjects related to biology concepts, such as humans, systems' investigations and their identification are challenging tasks. In conducting this study, there are two main limitations.

On the one hand, according to all conducted studies and tries to identify the potential source of biases on cuff-base BP technologies, we could mention only part of them in the previous sections. On the other hand, we are sure there are many unknown potential sources of biases due to the complexity of the human body, especially cardiovascular function and its output, BP. Also, in gathering information and reviewing research related to this topic from different sources and online databases, we found many articles that don't mention the bias term in BP measurement devices. In other words, their purposes differ from this study's aim. They have examined the effect of an issue, such as the difference in reported BP values on the left and right arms. Although we did our best to cover the most important potential sources of biases, there are probably some papers that we didn't mention to them. Also, the results of BP studies can be reported according to different standards, but we just focused on popular criteria (mean error and standard deviation).

On the other hand, in investigating complicated systems and the effect of each item on them, we should keep constant all related items except one. After that, we can describe and evaluate the system's performance by changing its values. Unfortunately, this approach cannot be followed in current work. For example, when researchers report about the effect of body position on BP values, we are unaware of the situation and conditions of the other potential sources of biases. Also, we cannot keep them in stable states. We mentioned that the time of the day is essential in measuring BP. For instance, it is impossible to measure BP from all participants in a study at a specific time.

VIII. CONCLUSION

BP, as one of the vital signs, has a lot of important information for physicians who make essential decisions about patients' treatments. They need accurate BP values because any difference in reported BP values can cause irreparable damage. In the last years, utilizing cuff-based BP technologies has increased widely due to the recommendations of home-based BP monitoring aims. Also, utilizing them in medical centers and hospitals is very common. In this study, we mentioned the difference between actual values of BP and reported ones using the "bias" term and addressed potential sources of bias in cuff-based BP devices. Most of the time, the reported BP values are inaccurate due to fundamental principles not being followed. It seems developing a new generation of cuff-based BP devices is necessary. We should develop new ML-based devices that detect bias and correct BP values.

REFERENCES

- [1] World Health Organization, "Cardiovascular Diseases (CVDs)," <https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-cvds>, 2021, accessed: 2021-06-21.
- [2] F. B. Ahmad and R. N. Anderson, "The leading causes of death in the US for 2020," *Jama*, vol. 325, no. 18, pp. 1829–1830, 2021.
- [3] R. Mukkamala, J.-O. Hahn, O. T. Inan, L. K. Mestha, C.-S. Kim, H. Toreyin, and S. Kyal, "Toward ubiquitous blood pressure monitoring via pulse transit time: theory and practice," *IEEE Transactions on Biomedical Engineering*, vol. 62, no. 8, pp. 1879–1901, 2015.
- [4] J. P. Kalehoff and S. Oparil, "The story of the silent killer," *Current Hypertension Reports*, vol. 22, no. 9, pp. 1–14, 2020.
- [5] S. Rastegar, H. GholamHosseini, and A. Lowe, "Non-invasive continuous blood pressure monitoring systems: current and proposed technology issues and challenges," *Physical and Engineering Sciences in Medicine*, vol. 43, no. 1, pp. 11–28, 2020.
- [6] W. H. Organization et al., "Who technical specifications for automated non-invasive blood pressure measuring devices with cuff. 2020," *World Health Organization*, pp. 1–68, 2020.
- [7] J. F. Van Den Heuvel, A. T. Lely, A. Franx, and M. N. Bekker, "Validation of the iHealth Track and Omron HEM-9210T automated blood pressure devices for use in pregnancy," *Pregnancy Hypertension*, vol. 15, pp. 37–41, 2019.
- [8] X.-R. Ding, N. Zhao, G.-Z. Yang, R. I. Pettigrew, B. Lo, F. Miao, Y. Li, J. Liu, and Y.-T. Zhang, "Continuous blood pressure measurement from invasive to unobtrusive: Celebration of 200th birth anniversary of Carl Ludwig," *IEEE journal of biomedical and health informatics*, vol. 20, no. 6, pp. 1455–1465, 2016.
- [9] K. Sewell, J. H. Halanych, L. B. Russell, S. J. Andreae, A. L. Cherrington, M. Y. Martin, M. Pisu, and M. M. Safford, "Blood pressure measurement biases in clinical settings, Alabama, 2010–2011," *Prev. Chronic Dis.*, vol. 13, no. 150348, p. E01, Jan. 2016.
- [10] K. M. Hoffman, S. Trawalter, J. R. Axt, and M. N. Oliver, "Racial bias in pain assessment and treatment recommendations, and false beliefs about biological differences between blacks and whites," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 113, no. 16, pp. 4296–4301, Apr. 2016.
- [11] P. Lee, M. Le Saux, R. Siegel, M. Goyal, C. Chen, Y. Ma, and A. C. Meltzer, "Racial and ethnic disparities in the management of acute pain in US emergency departments: Meta-analysis and systematic review," *Am. J. Emerg. Med.*, vol. 37, no. 9, pp. 1770–1777, Sep. 2019.
- [12] V. S. M. Valbuena, R. M. Merchant, and C. L. Hough, "Racial and ethnic bias in pulse oximetry and clinical outcomes," *JAMA Intern. Med.*, vol. 182, no. 7, pp. 699–700, Jul. 2022.
- [13] Z. Obermeyer, B. Powers, C. Vogeli, and S. Mullainathan, "Dissecting racial bias in an algorithm used to manage the health of populations," *Science*, vol. 366, no. 6464, pp. 447–453, Oct. 2019.
- [14] M. A. Reyna, E. O. Nsoesie, and G. D. Clifford, "Rethinking algorithm performance metrics for artificial intelligence in diagnostic medicine," *JAMA*, vol. 328, no. 4, pp. 329–330, Jul. 2022.
- [15] K. N. Vokinger, S. Feuerriegel, and A. S. Kesselheim, "Mitigating bias in machine learning for medicine," *Commun Med (Lond)*, vol. 1, no. 1, p. 25, Aug. 2021.
- [16] S. Magder, "The meaning of blood pressure," *Crit. Care*, vol. 22, no. 1, p. 257, Oct. 2018.
- [17] P. A. Iaizzo, *Handbook of cardiac anatomy, physiology, and devices*. Springer Science & Business Media, 2010.
- [18] S. S. Mousavi, M. Charimi, M. Firouzmand, M. Hemmati, M. Moghadam, and Y. Ghorbani, "Designing and manufacturing a mobile-based ambulatory monitoring of blood pressure using electrocardiogram and photoplethysmography signals," *Zanjan University*, 2018.
- [19] M. Lowry and S. Ashelford, "Assessing the pulse rate in adult patients," *Nursing Times*, vol. 111, no. 36–37, pp. 18–20, 2015.
- [20] J. Betts, P. Desaix, E. Johnson, J. Johnson, O. Korol, D. Kruse, B. Poe, J. Wise, M. Womble, and K. Young, "Anatomy and Physiology. OpenStax, 2013."
- [21] C. Vlachopoulos, M. O'Rourke, and W. W. Nichols, *McDonald's blood flow in arteries*, 6th ed., R. Reneman, Ed. London, England: Hodder Arnold, Jul. 2011.
- [22] J. L. Lapum, M. Verkuy, W. Garcia, O. St-Amant, and A. Tan, *Vital sign measurement across the lifespan*. Ryerson university, 2018.
- [23] A. Sapra, A. Malik, and P. Bhandari, "Vital sign assessment," in *StatPearls [Internet]*. StatPearls Publishing, 2021.
- [24] P. DeSaix, G. J. Betts, E. Johnson, J. E. Johnson, K. Oksana, D. H. Kruse, B. Poe, J. A. Wise, and K. A. Young, "Anatomy & Physiology (OpenStax)," 2013.
- [25] S. Glasser, "Vascular compliance and cardiovascular disease A risk factor or a marker?" *Am. J. Hypertens.*, vol. 10, no. 10, pp. 1175–1189, Oct. 1997.
- [26] H. Bazett, "The time relations of the blood-pressure changes after excision of the adrenal glands, with some observations on blood volume changes," *The Journal of Physiology*, vol. 53, no. 5, p. 320, 1920.
- [27] R. L. Letcher, S. Chien, T. G. Pickering, J. E. Sealey, and J. H. Laragh, "Direct relationship between blood pressure and blood viscosity in normal and hypertensive subjects. Role of fibrinogen and concentration," *Am. J. Med.*, vol. 70, no. 6, pp. 1195–1202, Jun. 1981.
- [28] P. Jeppesen, J. Sanye-Hajari, and T. Bek, "Increased blood pressure induces a diameter response of retinal arterioles that increases with decreasing arteriolar diameter," *Invest. Ophthalmol. Vis. Sci.*, vol. 48, no. 1, pp. 328–331, Jan. 2007.
- [29] T. Azegami, K. Uchida, M. Tokumura, and M. Mori, "Blood pressure tracking from childhood to adulthood," *Frontiers in Pediatrics*, vol. 9, 2021.
- [30] P. K. Whelton, R. M. Carey, W. S. Aronow, D. E. Casey, K. J. Collins, C. Dennison Himmelfarb, S. M. DePalma, S. Gidding, K. A. Jamerson, D. W. Jones et al., "2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APHA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines," *Journal of the American College of Cardiology*, vol. 71, no. 19, pp. e127–e248, 2018.
- [31] A. V. Chobanian, G. L. Bakris, H. R. Black, W. C.ushman, L. A. Green, J. L. Izzo, D. W. Jones, B. J. Materson, S. Oparil, J. T. Wright, and E. J. R. and, "Seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure," *Hypertension*, vol. 42, no. 6, pp. 1206–1252, Dec. 2003. [Online]. Available: <https://doi.org/10.1161/01.hyp.0000107251.49515.c2>

- [32] P. K. Whelton, R. M. Carey, W. S. Aronow, D. E. Casey, K. J. Collins, C. D. Himmelfarb, S. M. DePalma, S. Gidding, K. A. Jamerson, D. W. Jones, E. J. MacLaughlin, P. Muntner, B. Ovbigele, S. C. Smith, C. C. Spencer, R. S. Stafford, S. J. Taler, R. J. Thomas, K. A. Williams, J. D. Williamson, and J. T. Wright, "2017 ACC/AHA/AAA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults," *Journal of the American College of Cardiology*, vol. 71, no. 19, pp. e127–e248, May 2018. [Online]. Available: <https://doi.org/10.1016/j.jacc.2017.11.006>
- [33] E. Cole, "Measuring central venous pressure," *Nurs. Stand.*, vol. 22, no. 7, pp. 40–42, 2007.
- [34] J. Webster, *Medical instrumentation: Application and design*. John Wiley & Sons, 2009.
- [35] R. Kumar, P. K. Dubey, A. Zafer, A. Kumar, and S. Yadav, "Past, present and future of blood pressure measuring instruments and their calibration," *Measurement (Lond.)*, vol. 172, no. 108845, p. 108845, Feb. 2021.
- [36] L. Peter, N. Noury, and M. Cerny, "A review of methods for non-invasive and continuous blood pressure monitoring: Pulse transit time method is promising?" *Irbm*, vol. 35, no. 5, pp. 271–282, 2014.
- [37] S. H. Lim and S. H. Kim, "Blood pressure measurements and hypertension in infants, children, and adolescents: from the postmercury to mobile devices," *Clin Exp Pediatr*, vol. 65, no. 2, pp. 73–80, Feb. 2022.
- [38] G. Ogedegbe and T. Pickering, "Principles and techniques of blood pressure measurement," *Cardiology clinics*, vol. 28, no. 4, pp. 571–586, 2010.
- [39] G. Geršak, A. Žemva, and J. Drnovšek, "A procedure for evaluation of non-invasive blood pressure simulators," *Medical & biological engineering & computing*, vol. 47, no. 12, pp. 1221–1228, 2009.
- [40] G. S. Stergiou, B. Alpert, S. Mieke, R. Asmar, N. Atkins, S. Eckert, G. Frick, B. Friedman, T. Graßl, T. Ichikawa *et al.*, "A universal standard for the validation of blood pressure measuring devices: Association for the advancement of medical Instrumentation/European society of Hypertension/International organization for standardization (AAMI/ESH/ISO) collaboration statement," *Hypertension*, vol. 71, no. 3, pp. 368–374, 2018.
- [41] C. Hassler and M. Burnier, "Circadian variations in blood pressure," *American journal of cardiovascular drugs*, vol. 5, no. 1, pp. 7–15, 2005.
- [42] S. Wagner, T. S. Toftegaard, and O. W. Bertelsen, "Challenges in blood pressure self-measurement," *Int. J. Telemed. Appl.*, vol. 2012, p. 437350, Mar. 2012.
- [43] G. S. Stergiou, P. Palatini, G. Parati, E. O'Brien, A. Januszewicz, E. Lurbe, A. Persu, G. Mancia, R. Kreutz, and European Society of Hypertension Council and the European Society of Hypertension Working Group on Blood Pressure Monitoring and Cardiovascular Variability, "2021 European Society of Hypertension practice guidelines for office and out-of-office blood pressure measurement," *J. Hypertens.*, vol. 39, no. 7, pp. 1293–1302, Jul. 2021.
- [44] J. Liu, Y. Li, J. Li, D. Zheng, and C. Liu, "Sources of automatic office blood pressure measurement error: a systematic review," *Physiol. Meas.*, vol. 43, no. 9, p. 09TR02, Sep. 2022.
- [45] P. Muntner, D. Shimbo, R. M. Carey, J. B. Charleston, T. Gaillard, S. Misra, M. G. Myers, G. Ogedegbe, J. E. Schwartz, R. R. Townsend *et al.*, "Measurement of blood pressure in humans: a scientific statement from the American Heart Association," *Hypertension*, vol. 73, no. 5, pp. e35–e66, 2019.
- [46] N. Kallioinen, A. Hill, M. S. Horswill, H. E. Ward, and M. O. Watson, "Sources of inaccuracy in the measurement of adult patients' resting blood pressure in clinical settings: a systematic review," *Journal of hypertension*, vol. 35, no. 3, p. 421, 2017.
- [47] ESH/ESC Task Force for the Management of Arterial Hypertension, "2013 practice guidelines for the management of arterial hypertension of the european society of hypertension (ESH) and the european society of cardiology (ESC): ESH/ESC task force for the management of arterial hypertension," *J. Hypertens.*, vol. 31, no. 10, pp. 1925–1938, Oct. 2013.
- [48] P. G. Yong and L. A. Geddes, "The effect of cuff pressure deflation rate on accuracy in indirect measurement of blood pressure with the auscultatory method," *J. Clin. Monit.*, vol. 3, no. 3, pp. 155–159, Jul. 1987.
- [49] C. Speechly, N. Bignell, and M. Turner, "Sphygmomanometer calibration: why, how and how often?" *Australian family physician*, vol. 36, no. 10, 2007.
- [50] M. J. Turner, A. B. Baker, and P. C. Kam, "Effects of systematic errors in blood pressure measurements on the diagnosis of hypertension," *Blood pressure monitoring*, vol. 9, no. 5, pp. 249–253, 2004.
- [51] E. H. Yayan and M. Zengin, "A key point in medical measurements: Device calibration and knowledge level of healthcare professionals," *vol*, vol. 13, pp. 1346–1354, 2020.
- [52] T. G. Pickering, J. E. Hall, L. J. Appel, B. E. Falkner, J. Graves, M. N. Hill, D. W. Jones, T. Kurtz, S. G. Sheps, and E. J. Roccella, "Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research," *Hypertension*, vol. 45, no. 1, pp. 142–161, 2005.
- [53] J. F. Reckelhoff, "Gender differences in the regulation of blood pressure," *Hypertension*, vol. 37, no. 5, pp. 1199–1208, May 2001.
- [54] Y. B. Somani, A. W. Baross, R. D. Brook, K. J. Milne, C. L. McGowan, and I. L. Swaine, "Acute response to a 2-minute isometric exercise test predicts the blood pressure-lowering efficacy of isometric resistance training in young adults," *Am. J. Hypertens.*, vol. 31, no. 3, pp. 362–368, Feb. 2018.
- [55] L. Olatunji, A. Aaron, O. Michael, and I. Oyeyipo, "Water ingestion affects orthostatic challenge-induced blood pressure and heart rate responses in young healthy subjects: gender implications," *Nigerian Journal of Physiological Sciences*, vol. 26, no. 1, 2011.
- [56] Y.-L. Kho, S.-G. Yi, E.-H. Lee, and M.-H. Chung, "Acute effects of tobacco and non-tobacco cigarette smoking on the blood pressure and heart rate," *Journal of Environmental Health Sciences*, vol. 32, no. 3, pp. 222–226, 2006.
- [57] E. Papakonstantinou, I. Kechribari, K. Sotirakoglou, P. Tarantilis, T. Gourdouchali, G. Michas, V. Kravvariti, K. Voumvourakis, and A. Zampelas, "Acute effects of coffee consumption on self-reported gastrointestinal symptoms, blood pressure and stress indices in healthy individuals," *Nutr. J.*, vol. 15, no. 1, p. 26, Mar. 2016.
- [58] C. R. Monnard and E. K. Grasser, "Water ingestion decreases cardiac workload time-dependent in healthy adults with no effect of gender," *Sci. Rep.*, vol. 7, no. 1, p. 7939, Aug. 2017.
- [59] S. G. Helfer and J. A. McCubbin, "Does gender affect the relation between blood pressure and pain sensitivity?" *International Journal of Behavioral Medicine*, vol. 8, no. 3, pp. 220–229, 2001.
- [60] G. A. Harshfield, B. S. Alpert, E. S. Willey, G. W. Somes, J. K. Murphy, and L. M. Dupaul, "Race and gender influence ambulatory blood pressure patterns of adolescents," *Hypertension*, vol. 14, no. 6, pp. 598–603, 1989.
- [61] V. A. Costa-Hong, H. C. S. Muela, T. A. Macedo, A. R. K. Sales, and L. A. Bortolotto, "Gender differences of aortic wave reflection and influence of menopause on central blood pressure in patients with arterial hypertension," *BMC cardiovascular disorders*, vol. 18, no. 1, pp. 1–6, 2018.
- [62] J. H. Ki, M. K. Oh, and S. H. Lee, "Differences in blood pressure measurements obtained using an automatic oscillometric sphygmomanometer depending on clothes-wearing status," *Korean J. Fam. Med.*, vol. 34, no. 2, pp. 145–151, Mar. 2013.
- [63] X. Wang, J. C. Poole, F. A. Treiber, G. A. Harshfield, C. D. Hanevold, and H. Snieder, "Ethnic and gender differences in ambulatory blood pressure trajectories: results from a 15-year longitudinal study in youth and young adults," *Circulation*, vol. 114, no. 25, pp. 2780–2787, Dec. 2006.
- [64] B. M. Song, H. C. Kim, J.-S. Shim, M. H. Lee, and D. P. Choi, "Inter-arm difference in brachial blood pressure in the general population of Koreans," *Korean Circ. J.*, vol. 46, no. 3, pp. 374–383, May 2016.
- [65] Y.-L. Lan and T.-L. Chen, "Prevalence of high blood pressure and its relationship with body weight factors among inpatients with schizophrenia in Taiwan," *Asian Nursing Research*, vol. 6, no. 1, pp. 13–18, 2012.
- [66] E. Privšek, M. Hellgren, L. Råstam, U. Lindblad, and B. Daka, "Epidemiological and clinical implications of blood pressure measured in seated versus supine position," *Medicine*, vol. 97, no. 31, 2018.
- [67] J. Cui, J. L. Hopper, and S. B. Harrap, "Genes and family environment explain correlations between blood pressure and body mass index," *Hypertension*, vol. 40, no. 1, pp. 7–12, 2002.
- [68] A. Vallée, A.-L. Perrine, V. Deschamps, J. Blacher, and V. Olié, "Relationship between dynamic changes in body weight and blood pressure: the ESTEBAN survey," *American Journal of Hypertension*, vol. 32, no. 10, pp. 1003–1012, 2019.
- [69] P. P. Giggey, C. R. Wendell, A. B. Zonderman, and S. R. Waldstein, "Greater coffee intake in men is associated with steeper age-related

- increases in blood pressure," *Am. J. Hypertens.*, vol. 24, no. 3, pp. 310–315, Mar. 2011.
- [70] B. Bourgeois, K. Watts, D. M. Thomas, O. Carmichael, F. B. Hu, M. Heo, J. E. Hall, and S. B. Heymsfield, "Associations between height and blood pressure in the United States population," *Medicine*, vol. 96, no. 50, 2017.
 - [71] W.-H. PAN, S. Nanias, A. Dyer, K. Liu, A. McDonald, J. A. Schoenberger, R. B. Shekelle, R. Stamler, and J. Stamler, "The role of weight in the positive association between age and blood pressure," *American journal of epidemiology*, vol. 124, no. 4, pp. 612–623, 1986.
 - [72] R. J. Carrico, S. S. Sun, A. P. Sima, and B. Rosner, "The predictive value of childhood blood pressure values for adult elevated blood pressure," *Open journal of pediatrics*, vol. 3, no. 2, p. 116, 2013.
 - [73] Q. He, Z. Y. Ding, D. Y.-T. Fong, and J. Karlberg, "Blood pressure is associated with body mass index in both normal and obese children," *Hypertension*, vol. 36, no. 2, pp. 165–170, 2000.
 - [74] S. K. Jena, M. Pattnaik *et al.*, "Relationship between body mass index and blood pressure in school students," *CHRISMED Journal of Health and Research*, vol. 5, no. 3, p. 187, 2018.
 - [75] J. E. Neter, B. E. Stam, F. J. Kok, D. E. Grobbee, and J. M. Geleijnse, "Influence of weight reduction on blood pressure: a meta-analysis of randomized controlled trials," *Hypertension*, vol. 42, no. 5, pp. 878–884, 2003.
 - [76] R. A. Tibana, G. B. Pereira, J. W. Navalta, M. Bottaro, and J. Prestes, "Acute effects of resistance exercise on 24-h blood pressure in middle aged overweight and obese women," *Int. J. Sports Med.*, vol. 34, no. 5, pp. 460–464, May 2013.
 - [77] K. Karatzi, V. G. Rontoyanni, A. D. Protogerou, A. Georgoulia, K. Xenos, J. Chrysou, P. P. Sfrikakis, and L. S. Sidossis, "Acute effects of beer on endothelial function and hemodynamics: a single-blind, crossover study in healthy volunteers," *Nutrition*, vol. 29, no. 9, pp. 1122–1126, Sep. 2013.
 - [78] F. Fantin, C. J. Bulpitt, M. Zamboni, E. Cheek, and C. Rajkumar, "Arterial compliance may be reduced by ingestion of red wine," *J. Hum. Hypertens.*, vol. 30, no. 1, pp. 68–72, Jan. 2016.
 - [79] M. Kayrak, M. S. Ulgem, M. Yazici, R. Yilmaz, K. Demir, Y. Dogan, H. Ozhan, Y. Alihanoglu, F. Koc, and S. Bodur, "A comparison of blood pressure and pulse pressure values obtained by oscillometric and central measurements in hypertensive patients," *Blood Press.*, vol. 19, no. 2, pp. 98–103, Apr. 2010.
 - [80] R. M. Cunha, J. Vilaça-Alves, M. V. Noletto, J. S. Silva, A. M. Costa, C. N. F. Silva, T. I. R. Póvoa, and A. M. Lehen, "Acute blood pressure response in hypertensive elderly women immediately after water aerobics exercise: A crossover study," *Clinical and Experimental Hypertension*, vol. 39, no. 1, pp. 17–22, 2017.
 - [81] R. Netea, J. Lenders, P. Smits, and T. Thien, "Both body and arm position significantly influence blood pressure measurement," *Journal of human hypertension*, vol. 17, no. 7, pp. 459–462, 2003.
 - [82] M. R. R. Talukder, S. Rutherford, D. Phung, M. Z. Islam, and C. Chu, "The effect of drinking water salinity on blood pressure in young adults of coastal Bangladesh," *Environmental pollution*, vol. 214, pp. 248–254, 2016.
 - [83] D. Xu, Y. Zhang, B. Wang, H. Yang, J. Ban, F. Liu, and T. Li, "Acute effects of temperature exposure on blood pressure: An hourly level panel study," *Environ. Int.*, vol. 124, pp. 493–500, Mar. 2019.
 - [84] R. R. Azar, A. H. Frangieh, J. Mroué, L. Bassila, M. Kasty, G. Hage, and Z. Kadri, "Acute effects of waterpipe smoking on blood pressure and heart rate: a real-life trial," *Inhal. Toxicol.*, vol. 28, no. 8, pp. 339–342, Jul. 2016.
 - [85] P. Krzesiński, A. Stańczyk, G. Gielerak, K. Piotrowicz, M. Banak, and A. Wójcik, "The diagnostic value of supine blood pressure in hypertension," *Archives of Medical Science*, vol. 12, no. 2, pp. 310–318, 2016.
 - [86] Y. Li, L. Thijs, Z.-Y. Zhang, K. Asayama, T. W. Hansen, J. Boggia, K. Björklund-Bodegård, W.-Y. Yang, T. J. Niiranen, A. Ntineri, F.-F. Wei, M. Kikuya, T. Ohkubo, E. Dolan, A. Hozawa, I. Tsuji, K. Stolarz-Skrzypek, Q.-F. Huang, J. D. Melgarejo, V. Tikhonoff, S. Malyutina, E. Casiglia, Y. Nikitin, L. Lind, E. Sandoya, L. Aparicio, J. Barochiner, N. Gilis-Malinowska, K. Narkiewicz, K. Kawecka-Jaszcz, G. E. Maestre, A. M. Jula, J. K. Johansson, T. Kuznetsova, J. Filipovský, G. Stergiou, J.-G. Wang, Y. Imai, E. O'Brien, J. A. Staessen, and International Database on Ambulatory and Home Blood Pressure in Relation to Cardiovascular Outcome Investigators, "Opposing age-related trends in absolute and relative risk of adverse health outcomes associated with out-of-office blood pressure," *Hypertension*, vol. 74, no. 6, pp. 1333–1342, Dec. 2019.
 - [87] K. A. Walker, A. R. Sharrett, A. Wu, A. L. C. Schneider, M. Albert, P. L. Lutsey, K. Bandeen-Roche, J. Coresh, A. L. Gross, B. G. Windham, D. S. Knopman, M. C. Power, A. M. Rawlings, T. H. Mosley, and R. F. Gottesman, "Association of midlife to late-life blood pressure patterns with incident dementia," *JAMA*, vol. 322, no. 6, pp. 535–545, Aug. 2019.
 - [88] M. E. Widlansky, J. A. Vita, M. J. Keyes, M. G. Larson, N. M. Hamburg, D. Levy, G. F. Mitchell, E. W. Osypiuk, R. S. Vasan, and E. J. Benjamin, "Relation of season and temperature to endothelium-dependent flow-mediated vasodilation in subjects without clinical evidence of cardiovascular disease (from the Framingham Heart Study)," *Am. J. Cardiol.*, vol. 100, no. 3, pp. 518–523, Aug. 2007.
 - [89] G. Barba, E. Troiano, P. Russo, P. Strazzullo, and A. Siani, "Body mass, fat distribution and blood pressure in Southern Italian children: results of the ARCA project," *Nutrition, metabolism and cardiovascular diseases*, vol. 16, no. 4, pp. 239–248, 2006.
 - [90] H. Sano, A. Hara, K. Asayama, S. Miyazaki, M. Kikuya, Y. Imai, and T. Ohkubo, "Antihypertensive drug effects according to the pre-treatment self-measured home blood pressure: the HOMED-BP study," *BMJ Open*, vol. 10, no. 12, p. e040524, Dec. 2020.
 - [91] S. Zheng, M. Z. Wang, Z. Y. Cheng, F. Kang, Y. H. Nie, X. Y. Mi, H. Y. Li, L. Jin, Y. W. Zhang, and Y. N. Bai, "Effects of outdoor temperature on blood pressure in a prospective cohort of northwest China," *Biomed. Environ. Sci.*, vol. 34, no. 2, pp. 89–100, Feb. 2021.
 - [92] Y. Kang, Y. Han, T. Guan, X. Wang, T. Xue, Z. Chen, L. Jiang, L. Zhang, C. Zheng, Z. Wang, R. Gao, and China Hypertension Survey investigators, "Clinical blood pressure responses to daily ambient temperature exposure in china: An analysis based on a representative nationwide population," *Sci. Total Environ.*, vol. 705, no. 135762, p. 135762, Feb. 2020.
 - [93] S. Lewington, L. Li, P. Sherliker, Y. Guo, I. Millwood, Z. Bian, G. Whitlock, L. Yang, R. Collins, J. Chen, X. Wu, S. Wang, Y. Hu, L. Jiang, L. Yang, B. Lacey, R. Peto, and Z. Chen, "Seasonal variation in blood pressure and its relationship with outdoor temperature in 10 diverse regions of China," *J. Hypertens.*, vol. 30, no. 7, pp. 1383–1391, Jul. 2012.
 - [94] S. T. Hardy, L. Chen, A. L. Cherrington, N. Moise, B. C. Jaeger, K. Foti, S. Sakhuja, G. Wozniak, M. Abdalla, and P. Muntner, "Racial and ethnic differences in blood pressure among US adults, 1999–2018," *Hypertension*, vol. 78, no. 6, pp. 1730–1741, 2021.
 - [95] C. D. Fryar, Y. Ostchega, C. M. Hales, G. Zhang, and D. Kruszon-Moran, "Hypertension prevalence and control among adults: United States, 2015–2016," *National Center for Health Statistics*, 2017.
 - [96] J. A. Staessen, L. Bieniaszewski, E. O'Brien, P. Gosse, H. Hayashi, Y. Imai, T. Kawasaki, K. Otsuka, P. Palatini, L. Thijs *et al.*, "Nocturnal blood pressure fall on ambulatory monitoring in a large international database. The 'Ad Hoc' Working Group," *Hypertension*, vol. 29, no. 1, pp. 30–39, 1997.
 - [97] J. Mayet, N. Chapman, C. K.-C. Li, M. Shahi, N. R. Poulter, P. S. Sever, R. A. Foale, and S. A. M. Thom, "Ethnic differences in the hypertensive heart and 24-hour blood pressure profile," *Hypertension*, vol. 31, no. 5, pp. 1190–1194, 1998.
 - [98] F. Routledge and J. Mc Fetridge-Durdle, "Nondipping blood pressure patterns among individuals with essential hypertension: a review of the literature," *European Journal of Cardiovascular Nursing*, vol. 6, no. 1, pp. 9–26, 2007.
 - [99] S. Ragot, N. Genes, L. Vaur, and D. Herpin, "Comparison of three blood pressure measurement methods for the evaluation of two anti-hypertensive drugs: feasibility, agreement, and reproducibility of blood pressure response," *Am. J. Hypertens.*, vol. 13, no. 6, pp. 632–639, Jun. 2000.
 - [100] K. Asayama, T. Ohkubo, H. Rakugi, M. Miyakawa, H. Mori, T. Katsuya, Y. Ikehara, S. Ueda, Y. Ohya, T. Tsuchihashi, K. Kario, K. Miura, S. Ito, S. Umemura, and Japanese Society of Hypertension Working Group on the Comparison of Self-measured home, Automated unattended office, Conventional attended office blood pressure (COSAC) study, "Direct comparison of the reproducibility of in-office and self-measured home blood pressures," *J. Hypertens.*, vol. 40, no. 2, pp. 398–407, Feb. 2022.
 - [101] M. Burnier, "Should we eat more potassium to better control blood pressure in hypertension?" *Nephrology Dialysis Transplantation*, vol. 34, no. 2, pp. 184–193, 2019.
 - [102] M. Nishiwaki, N. Kora, and N. Matsumoto, "Ingesting a small amount of beer reduces arterial stiffness in healthy humans," *Physiol. Rep.*, vol. 5, no. 15, Aug. 2017.
 - [103] M. K. McMullen, J. M. Whitehouse, G. Shine, and A. Towell, "Habitual coffee and tea drinkers experienced increases in blood pressure after

- consuming low to moderate doses of caffeine; these increases were larger upright than in the supine posture,” *Food Funct.*, vol. 2, no. 3–4, pp. 197–203, Apr. 2011.
- [104] J. R. Carter, S. F. Stream, J. J. Durocher, and R. A. Larson, “Influence of acute alcohol ingestion on sympathetic neural responses to orthostatic stress in humans,” *Am. J. Physiol. Endocrinol. Metab.*, vol. 300, no. 5, pp. E771–8, May 2011.
- [105] D. Nowak, M. Gośliński, A. Wesołowska, K. Berenda, and C. Popławski, “Effects of acute consumption of Noni and chokeberry juices vs. Energy drinks on blood pressure, heart rate, and blood glucose in young adults,” *Evid. Based. Complement. Alternat. Med.*, vol. 2019, p. 6076751, Aug. 2019.
- [106] A. LUQMAN and M. KHAN, “An experimental study of short-term physiological effects of a single dose of energy drink in healthy male medical students,” *Pakistan Journal of Medical and Health Sciences*, vol. 13, p. 685–9, 2019.
- [107] J. F. Buckman, D. Eddie, E. G. Vascillo, B. Vascillo, A. Garcia, and M. E. Bates, “Immediate and complex cardiovascular adaptation to an acute alcohol dose,” *Alcohol. Clin. Exp. Res.*, vol. 39, no. 12, pp. 2334–2344, Dec. 2015.
- [108] I. M. Hower, S. A. Harper, and T. W. Buford, “Circadian rhythms, exercise, and cardiovascular health,” *Journal of circadian rhythms*, vol. 16, 2018.
- [109] J.-M. Boivin, E. Boutte, R. Fay, P. Rossignol, and F. Zannad, “Home blood pressure monitoring: a few minutes of rest before measurement may not be appropriate,” *Am. J. Hypertens.*, vol. 27, no. 7, pp. 932–938, Jul. 2014.
- [110] P. M. Jansen, M. J. Leineweber, and T. Thien, “The effect of a change in ambient temperature on blood pressure in normotensives,” *J. Hum. Hypertens.*, vol. 15, no. 2, pp. 113–117, Feb. 2001.
- [111] L. Yang, L. Li, S. Lewington, Y. Guo, P. Sherliker, Z. Bian, R. Collins, R. Peto, Y. Liu, R. Yang, Y. Zhang, G. Li, S. Liu, Z. Chen, and China Kadoorie Biobank Study Collaboration, “Outdoor temperature, blood pressure, and cardiovascular disease mortality among 23000 individuals with diagnosed cardiovascular diseases from China,” *Eur. Heart J.*, vol. 36, no. 19, pp. 1178–1185, May 2015.
- [112] S. Wu, F. Deng, J. Huang, X. Wang, Y. Qin, C. Zheng, H. Wei, M. Shima, and X. Guo, “Does ambient temperature interact with air pollution to alter blood pressure? A repeated-measure study in healthy adults,” *J. Hypertens.*, vol. 33, no. 12, pp. 2414–2421, Dec. 2015.
- [113] Y.-M. Kim, S. Kim, H.-K. Cheong, B. Ahn, and K. Choi, “Effects of heat wave on body temperature and blood pressure in the poor and elderly,” *Environ. Health Toxicol.*, vol. 27, p. e2012013, Jul. 2012.
- [114] H. Hinghofer-Szalkay, “Gravity, the hydrostatic indifference concept and the cardiovascular system,” *Eur. J. Appl. Physiol.*, vol. 111, no. 2, pp. 163–174, Feb. 2011.
- [115] A. Al-Qatatsheh, Y. Morsi, A. Zavabeti, A. Zolfagharian, N. Salim, A. Z. Kouzani, B. Mosadegh, and S. Gharaie, “Blood pressure sensors: Materials, fabrication methods, performance evaluations and future perspectives,” *Sensors (Basel)*, vol. 20, no. 16, p. 4484, Aug. 2020.
- [116] P. Sareen, K. Saxena, B. Sareen, and B. Taneja, “Comparison of arm and calf blood pressure,” *Indian Journal of Anaesthesia*, vol. 56, no. 1, p. 83, 2012.
- [117] İ. Eşer, L. Khorshid, Ü. Yapucu Güneş, and Y. Demir, “The effect of different body positions on blood pressure,” *Journal of Clinical Nursing*, vol. 16, no. 1, pp. 137–140, 2007.
- [118] K. Chachula, F. Lieb, F. Hess, J. Welter, N. Graf, and A. Dullenkopf, “Non-invasive continuous blood pressure monitoring (ClearSight™ system) during shoulder surgery in the beach chair position: a prospective self-controlled study,” *BMC Anesthesiol.*, vol. 20, no. 1, p. 271, Oct. 2020.
- [119] R. T. Netea, P. Smits, J. W. Lenders, and T. Thien, “Does it matter whether blood pressure measurements are taken with subjects sitting or supine?” *Journal of hypertension*, vol. 16, no. 3, pp. 263–268, 1998.
- [120] G. Cicolini, C. Pizzi, E. Palma, M. Bucci, F. Schioppa, A. Mezzetti, and L. Manzoli, “Differences in blood pressure by body position (supine, fowler’s, and sitting) in hypertensive subjects,” *American journal of hypertension*, vol. 24, no. 10, pp. 1073–1079, 2011.
- [121] R. Netea, J. Lenders, P. Smits, and T. Thien, “Arm position is important for blood pressure measurement,” *Journal of human hypertension*, vol. 13, no. 2, pp. 105–109, 1999.
- [122] L. Foster-Fitzpatrick, A. Ortiz, H. Sibilano, R. Marcantonio, and L. T. Braun, “The effects of crossed leg on blood pressure measurement,” *Nurs. Res.*, vol. 48, no. 2, pp. 105–108, Mar. 1999.
- [123] R. Pinar, N. Sabuncu, and A. Oksay, “Effects of crossed leg on blood pressure,” *Blood Press.*, vol. 13, no. 4, pp. 252–254, 2004.
- [124] D. Lane, M. Beevers, N. Barnes, J. Bourne, A. John, S. Malins, and D. G. Beevers, “Inter-arm differences in blood pressure: when are they clinically significant,” *Journal of hypertension*, vol. 20, no. 6, pp. 1089–1095, 2002.
- [125] C. Bakx, G. Oerlemans, H. van den Hoogen, C. van Weel, and T. Thien, “The influence of cuff size on blood pressure measurement,” *J. Hum. Hypertens.*, vol. 11, no. 7, pp. 439–445, Jul. 1997.
- [126] E. A. Perez Alday, A. B. Rad, M. A. Reyna, N. Sadr, A. Gu, Q. Li, M. Dumitru, J. Xue, D. Albert, R. Sameni, and G. D. Clifford, “Age, sex and race bias in automated arrhythmia detectors,” *J. Electrocardiol.*, vol. 74, pp. 5–9, Sep. 2022.
- [127] R. Mukkamala and J.-O. Hahn, “Toward ubiquitous blood pressure monitoring via pulse transit time: Predictions on maximum calibration period and acceptable error limits,” *IEEE Trans. Biomed. Eng.*, vol. 65, no. 6, pp. 1410–1420, Jun. 2018.
- [128] D.-H. Nam, W.-B. Lee, Y.-S. Hong, and S.-S. Lee, “Measurement of spatial pulse wave velocity by using a clip-type pulsimeter equipped with a hall sensor and photoplethysmography,” *Sensors*, vol. 13, no. 4, pp. 4714–4723, 2013.
- [129] Y. Zhang, Y. Li, X. Chen, and N. Deng, “Mechanism of magnetic pulse wave signal for blood pressure measurement,” *Journal of Biomedical Science and Engineering*, vol. 9, no. 10, pp. 29–36, 2016.
- [130] Z. Chen, X. Yang, J. T. Teo, and S. H. Ng, “Noninvasive monitoring of blood pressure using optical ballistocardiography and photoplethysmograph approaches,” in *2013 35th annual international conference of the IEEE engineering in medicine and biology society (EMBC)*. IEEE, 2013, pp. 2425–2428.
- [131] S.-H. Liu, D.-C. Cheng, and C.-H. Su, “A cuffless blood pressure measurement based on the impedance plethysmography technique,” *Sensors*, vol. 17, no. 5, p. 1176, 2017.
- [132] S. Chen, Z. Ji, H. Wu, and Y. Xu, “A non-invasive continuous blood pressure estimation approach based on machine learning,” *Sensors*, vol. 19, no. 11, p. 2585, 2019.
- [133] S. S. Mousavi, M. Firouzmmand, M. Charimi, M. Hemmati, M. Moghadam, and Y. Ghorbani, “Blood pressure estimation from appropriate and inappropriate ppg signals using a whole-based method,” *Biomedical Signal Processing and Control*, vol. 47, pp. 196–206, 2019.

TABLE VIII: The results of studies on the effect of eating, drinking, or smoking on BP values

Ref.	N	Conditions	SBP	DBP
[102]	11	Before drinking AF200 ^a	120 ± 9.9	69 ± 3.3
		90 minute after drinking AF200	123 ± 6.6	74 ± 3.3
[102]	11	Before drinking AF350 ^b	125 ± 6.6	72 ± 6.6
		90 minute after drinking AF350	125 ± 9.9	74 ± 6.6
[102]	11	Before drinking B200 ^c	124 ± 9.9	71 ± 6.6
		90 minute after drinking B200	122 ± 9.9	74 ± 6.6
[102]	11	Before drinking B350 ^d	123 ± 6.6	71 ± 6.6
		90 minute after drinking B350	123 ± 9.9	76 ± 13.2
[103]	12	Before drinking placebo	133.5 ± 14.1	86.4 ± 8.7
		After drinking placebo	131.5 ± 11.8	82.9 ± 8.4
[103]	12	Before drinking C67 ^f	127.6 ± 9.1	81.9 ± 6.7
		After drinking C67	135.6 ± 10.1	84.7 ± 6.0
[103]	12	Before drinking C133 ^g	126.9 ± 11.1	81.4 ± 7.7
		After drinking C133	137.6 ± 14.1	86.5 ± 8.2
[103]	12	Before drinking C200 ^h	127.5 ± 10.2	81.1 ± 5.5
		After drinking C200	132.7 ± 10.7	83.5 ± 8.2
[104]	15	Pre-treatment of alcohol	120 ± 11.6	64 ± 7.74
		Post-treatment of alcohol	124 ± 15.49	69 ± 7.74
[104]	15	Pre-treatment of placebo	117 ± 7.74	64 ± 11.6
		Post-treatment of placebo	123 ± 7.74	71 ± 7.74
[78]	18	Before drinking alcohol ^e	110.3 ± 12.0	80.0 ± 8.0
		After drinking alcohol	109.5 ± 11.4	76.2 ± 7.1
[105]	22	Before drinking noni juice	119.6 ± 8.3	77.0 ± 6.6
		After drinking noni juice	113.6 ± 8.5	72.0 ± 4.8
[105]	22	Before drinking chokeberry juice	125.6 ± 14	84.0 ± 9.8
		After drinking chokeberry juice	124.3 ± 16.1	81.0 ± 9.9
[105]	22	Before consuming energy drink	119.2 ± 14.8	73.9 ± 8.4
		After consuming energy drink	124.8 ± 14.1	84.8 ± 9.9
[105]	22	Before drinking water	124.3 ± 13.5	77.7 ± 9.2
		After drinking water	124.0 ± 11.4	75.8 ± 8.0
[106]	35	Before drinking STING ^j	122.94 ± 14.90	78.71 ± 10.53
		After drinking STING	123.71 ± 14.45	78.20 ± 9.80
[55]	37	Before drinking 50 ml water	119.6 ± 11.5	74.1 ± 10.1
		After drinking 50 ml water	122.5 ± 11.6	77.3 ± 7.7
[55]	37	Before drinking 500 ml water	116.9 ± 8.6	73.8 ± 10.0
		After drinking 500 ml water	125.8 ± 8.8	76.8 ± 10.7
[56]	39	Before non-tobacco smoking	120 ± 13.5	78.9 ± 10.1
		65 minute after non-tobacco smoking	114 ± 11.4	76.6 ± 6.9
[56]	39	Before tobacco smoking	118.6 ± 12.8	79.7 ± 9.2
		65 minute after tobacco smoking	116.9 ± 12.4	80.0 ± 8.9
[57]	40	Before drinking 200 ml cold espresso	116.67 ± 9.73	75.27 ± 7.08
		After drinking 200 ml cold espresso	120.03 ± 11.13	79.54 ± 9.10
[57]	40	Before drinking 200 ml filter coffee	118.21 ± 12.33	77.09 ± 8.53
		After drinking 200 ml filter coffee	121.17 ± 10.62	79.05 ± 6.70
[57]	40	Before drinking 200 ml cold instant coffee	116.74 ± 12.33	77.33 ± 8.47
		After drinking 200 ml cold instant coffee	121.34 ± 11.38	79.63 ± 7.27
[57]	40	Before drinking 200 ml hot instant coffee	118.53 ± 10.49	78.15 ± 9.29
		After drinking 200 ml hot instant coffee	122.62 ± 11.82	80.19 ± 8.72
[106]	60	Before drinking STING ⁱ	121.18 ± 14.32	77.38 ± 9.61
		After drinking STING	126.50 ± 14.12	80.98 ± 9.01
[107]	72	Pre beverage of juice	117 ± 13.1	79.8 ± 10.1
		Post beverage of juice	125.9 ± 13.2	85.4 ± 9.6
[107]	72	Pre beverage of placebo	126.2 ± 19.2	83.5 ± 13.9
		Post beverage of placebo	130.7 ± 18.2	85.7 ± 12.9
[107]	72	Pre beverage of alcohol	116.9 ± 13.5	80.1 ± 8.7
		Post beverage of alcohol	113.2 ± 12.6	79.9 ± 9.7
[84]	194	Before water-pipe smoking	120.3 ± 15.8	76.4 ± 11.3
		15 minute after water-pipe smoking	121.1 ± 16.1	77.1 ± 10.8

^a 200 mL of alcohol-free beer; ^b 350 mL of alcohol-free beer; ^c 200 mL of beer; ^d 350 mL of beer; ^e Two glasses (2 × 125 mL) of red wine (12% of ethanol);^f 67 mg of caffeine; ^g 133 mg of caffeine; ^h 200 mg of caffeine; ⁱ a single dose (500 mL) of energy drink; ^j a 2-glasses (500 mL) of plain water

TABLE IX: The results of studies that investigate the effect of the circadian clock on blood pressure values

Ref.	N	Mean daytime BP		Mean nighttime BP	
		SBP	DBP	SBP	DBP
[97]	46	149 ± 18.3	95 ± 10.7	132 ± 21.7	81 ± 13.5
[97]	46	145 ± 14.9	95 ± 11.5	136 ± 17.6	86 ± 11.5
[85]	280	144.7 ± 11.9	91.0 ± 8.6	128.2 ± 12.9	77.8 ± 9.0
[63]	312	119.5 ± 8.8	72.5 ± 6.6	108.7 ± 9.3	60.4 ± 7.2
[63]	351	117.7 ± 8.1	70.9 ± 6.4	105.9 ± 8.4	57.7 ± 6.1
[86]	17921	129.3 ± 15.1	78.8 ± 9.3	112.9 ± 15.6	65.1 ± 9.6

TABLE X: The results of studies that investigate the effect of ambient temperature on blood pressure values.

Ref.	N	Temp. (°C)	SBP	DBP
[110]	19	7.5 ± 0.7	118 ± 7.8	65 ± 6.1
[110]	20	14.8 ± 1.3	116 ± 6.3	64 ± 5.4
[110]	20	2.0 ± 0.4	121 ± 7.6	65 ± 6.3
[110]	20	-3.4 ± 3.0	125 ± 18.0	67 ± 5.8
[112]	39	25.0	117	65
[112]	39	17.6	117	66
[112]	39	22.7	122	65
[112]	39	21.6	119	65
[83]	100	15.7 ± 8.7	132.9 ± 16.5	80.0 ± 10.4
[113]	327	31.5 ± 1.0	133.7 ± 24.5	81.7 ± 15.4
[88]	500	25 ± 1	123 ± 17	70 ± 11
[88]	599	24 ± 1	128 ± 18	72 ± 12
[88]	733	26 ± 1	122 ± 17	69 ± 11
[88]	755	25 ± 1	124 ± 18	71 ± 11

TABLE XI: The results of studies that investigate the effect of the body points on recorded blood pressure values

Ref.	N	Measuring place	SBP	DBP
[79]	45	Upper Arm	174.0 ± 14.1	95.8 ± 11.5
		Wrist	163.8 ± 25.4	94.4 ± 11.5
[79]	70	Upper Arm	168.3 ± 18.4	83.4 ± 9.4
		Wrist	159.2 ± 18.5	83.2 ± 10.5
[116]	250	Arm	127.72 ± 15.65	80.67 ± 11.12
		Leg	142.97 ± 22.18	75.66 ± 11.89

TABLE XII: The results of studies that compare BP values according to different positions of people during the measurement

Ref.	N	Body position	SBP	DBP
[103]	12	Supine	116.2 ± 11.7	68.1 ± 6.6
		Upright	133.5 ± 14.1	86.4 ± 8.7
[81]	57	Sitting	135.7 ± 24.8	79.5 ± 9.7
		Supine	141.3 ± 25.5	84.6 ± 10.5
[117]	157	Sitting	102.8 ± 11.4	65.7 ± 8.2
		Standing	99.9 ± 10.2	66.0 ± 8.7
		Supine	107.9 ± 10.7	66.9 ± 9.6
		Supine; legs crossed	107.0 ± 8.6	66.7 ± 7.3
[118]	229	Supine	129.8 ± 27.5	72.4 ± 14.5
		Beach chair	114.6 ± 24.8	64.6 ± 11.2
[119]	245	Sitting	136.7 ± 21.9	86.0 ± 14
		Supine	135.5 ± 20.3	83.5 ± 12.5
[120]	250	Supine	139.3 ± 14.0	80.1 ± 9.1
		Fowler's	138.1 ± 13.8	81.9 ± 9.4
		Sitting	137.2 ± 13.7	83.0 ± 9.6
[66]	1298	Sitting	125.9 ± 14.9	76.1 ± 10.2
		Supine	124.7 ± 14.1	71.7 ± 9.0

TABLE XIII: The results of studies that investigate the effect of the arm position on blood pressure values

Ref.	N	Arm position	SBP	DBP
[81]	57	Arm high (at heart level)	137.4 ± 29.0	78.2 ± 14.4
		Arm low (on the bed)	142.1 ± 28.0	82.1 ± 13.4
[121]	69	Arm high (at heart level)	133.3 ± 20.7	77.7 ± 9.9
		Arm low (on the arm-rest of chair)	143.0 ± 19.9	88.6 ± 9.1

TABLE XIV: The results of studies that investigate the effect of the various legs position on blood pressure values

Ref.	N	Leg position	SBP	DBP
[122]	100	Uncrossed	146.47 ± 18.60	80.90 ± 11.19
		Crossed	155.54 ± 19.34	84.86 ± 11.57
[123]	238	Uncrossed	145.12 ± 20.33	86.38 ± 10.81
		Crossed	153.62 ± 20.20	92.10 ± 11.20

TABLE XV: The results of studies that investigate the effect of measuring BP values in different arms

Ref.	N	Right arm	Left arm
[81]	57	SBP : 138.3 ± 29.2 DBP : 77.8 ± 13.7	SBP : 137.4 ± 29.0 DBP : 78.2 ± 14.4
[121]	69	SBP : 133.3 ± 20.7 DBP : 77.7 ± 9.9	SBP : 131.8 ± 19.1 DBP : 78.0 ± 9.9
[124]	400	SBP : 131.2 ± 21.0 DBP : 76.8 ± 11.9	SBP : 129.4 ± 21.2 DBP : 77.1 ± 12.6

TABLE XVI: The results of studies that investigate the effect of the arm position on BP values

Ref.	N	Cuff size (cm)	SBP	DBP
[125]	130	13 × 36	125.1 ± 19.2	75.4 ± 12.4
		16 × 23	123.7 ± 19.7	74.4 ± 13.2
		13 × 23	127.2 ± 19.2	77.0 ± 12.8

TABLE XVII: The results of studies that investigate the impact of resting for 5 minutes before measuring BP

Ref.	N	Before resting	After resting
[109]	52	SBP : 127.9 ± 12.0 DBP : 78.0 ± 8.7	SBP : 121.5 ± 10.9 DBP : 76.0 ± 9.0

TABLE XVIII: The results of studies that investigate the effect of the cloth on the arm on BP values

Ref.	N	Measuring place	SBP	DBP
[62]	141	Sleeved	128.5 ± 10.6	80.7 ± 6.3
		Rolled sleeves	128.3 ± 11.1	80.9 ± 6.3
		Bare arm	128.4 ± 10.8	80.8 ± 6