

Ambulatory Blood Pressure Values Corresponding to the 2024 ESC Blood Pressure Categories in a Tunisian Population: A cross-sectional study

Seuils de pression artérielle ambulatoire pour la classification de l'hypertension

Awatef Sassi¹, Souhir Chelly³, Imen Bouhlel^{1,2}, Mohamed Aymen Ben Abdesslem^{1,2}, Aicha Laouani^{4,5}, Maher Garbi⁶, Saad Saguem^{4,5}, Abdallah Mahdhaoui^{1,2}

1. University of Sousse, Faculty of Medicine of Sousse, 4000, Laboratory of Cardiopulmonary System Interactions LR14ES05, Sousse, Tunisia.
2. University of Sousse, Faculty of Medicine of Sousse, 4000, Farhat Hached Hospital, Service of Cardiology, Laboratory of Cardiopulmonary System Interactions LR14ES05, Sousse, Tunisia.
3. University of Sousse, Faculty of Medicine of Sousse, 4000, Farhat Hached Hospital, Service of Infection Prevention and Control, Laboratory of Cytogenetics, Molecular Genetics, and Human Reproductive Biology LR03SP02, Sousse, Tunisia.
4. University of Sousse, Faculty of Medicine of Sousse, 4000. Laboratory of Metabolic Biophysics and Applied Pharmacology, Sousse, Tunisia
5. University of Sousse, Faculty of Medicine of Sousse, USCR Analytical Platform UHPLC-MS & Research in Medicine and Biology, Sousse, Tunisia
6. University of Sousse, Faculty of Medicine of Sousse, Department of Family Medicine, Sousse, Tunisia

ABSTRACT

Background: Considerable progress has been made in defining thresholds for ambulatory blood pressure monitoring (ABPM) that are equivalent to office blood pressure measurements (OBPM). However, standardized ABPM thresholds for different stages of hypertension are still lacking in specific populations, including Tunisians. The aim was to determine ABPM values corresponding to the elevated blood pressure and hypertension categories of the 2024 ESC classification, and to provide local reference data for the Tunisian population.

Methods: It was a cross-sectional study involving Tunisian adults. Participants underwent blood pressure assessment using conventional sphygmomanometer, followed by 24-hour ABPM. Office blood pressure was classified according to the 2024 ESC categories (non-elevated, elevated, hypertension). ABPM values corresponding to the elevated blood pressure and hypertension boundaries were identified using receiver operating characteristic (ROC) curve analysis to determine optimal cut-off values.

Results: A total of 403 were included, 274 men (68%) and 129 women (32%) with a mean age of 49.01 ± 12.44 years. Corresponding ABPM values for the elevated BP and hypertension boundaries, rounded to the nearest whole mmHg for clinical applicability, were, respectively: 121/67 mm Hg and 128/73 mm Hg for the 24-hour period; 125/71 mm Hg and 131/73 mm Hg for daytime; and 112/65 mm Hg and 112/66 mm Hg for nighttime.

Conclusion: To our knowledge, this is the first study conducted in Tunisia to determine ABPM values corresponding to the 2024 ESC blood pressure categories, based on real-world clinical data. The value identified for the elevated BP boundary was closely consistent with the ESC 2024 reference values, while the value corresponding to the hypertension boundary was somewhat lower. These findings provide local observational data on the relationship between office and ambulatory blood pressure measurements in a Tunisian population; broader application to other Maghreb countries would require external validation.

Key words: Ambulatory Blood Pressure Monitoring; Reference Values; Diagnosis; Hypertension.

RÉSUMÉ

Contexte : Des progrès considérables ont été réalisés dans la définition de seuils de pression artérielle ambulatoire (PAA) équivalents à ceux des mesures de pression artérielle au cabinet médical (MAPA). Cependant, des seuils de PAA standardisés pour les différents stades d'hypertension font encore défaut dans certaines populations, notamment en Tunisie. L'objectif de cette étude était d'établir des seuils de PAA pour différents degrés d'hypertension dans la population tunisienne.

Méthodes : Il s'agissait d'une étude transversale menée auprès d'adultes tunisiens. Les participants ont subi une mesure de la pression artérielle à l'aide d'un sphygmomanomètre à mercure classique, suivie d'un enregistrement ambulatoire de la pression artérielle (MAPA) sur 24 heures. Les seuils de MAPA pour chaque grade d'hypertension ont été identifiés par rapport à la pression artérielle mesurée au cabinet médical (PAC) à l'aide d'une analyse de la courbe ROC (Receiver Operating Characteristic) afin de déterminer les valeurs seuils optimales.

Résultats : Au total, 403 participants ont été inclus, dont 274 hommes (68 %) et 129 femmes (32 %), d'un âge moyen de $49,01 \pm 12,44$ ans. Les seuils de pression artérielle au cabinet médical (OBPM) pour l'hypertension de grade 1, 2 et 3 sont respectivement de 140/90 mmHg, 160/100 mmHg et 180/110 mmHg. Concernant les mesures ambulatoires de la pression artérielle (ABPM), les seuils sur 24 heures sont de 127,5/75,5 mmHg, 136,5/82,5 mmHg et 146,5/88,5 mmHg pour les grades 1, 2 et 3, respectivement ; les seuils diurnes sont respectivement de 132,5/79,5 mmHg, 143,5/86,5 mmHg et 157,5/90,5 mmHg. et les seuils nocturnes sont respectivement de 111,5/63,5 mm Hg, 138,5/70,5 mm Hg et 145,5/69,5 mm Hg.

Conclusion : À notre connaissance, il s'agit de la première étude menée en Tunisie visant à établir des seuils de MAPA spécifiques à chaque grade, à partir de données cliniques réelles. Compte tenu des similitudes démographiques, culturelles et socio-économiques au sein de la région du Maghreb, ces résultats pourraient constituer une référence précieuse non seulement pour la Tunisie, mais aussi pour les pays voisins.

Mots clés: Surveillance ambulatoire de la pression artérielle, Valeurs de référence, Diagnostic, Hypertension

Correspondance

Souhir Chelly

University of Sousse, Faculty of Medicine of Sousse, 4000, Farhat Hached Hospital, Service of Infection Prevention and Control, Laboratory of Cytogenetics, Molecular Genetics, and Human Reproductive Biology LR03SP02, Sousse, Tunisia.

Email: souhirsch@hotmail.fr

INTRODUCTION

Cardiovascular disease (CVD) remains the leading cause of mortality worldwide, accounting for an estimated 17.9 million deaths annually (1). Hypertension, the most prevalent form of CVD, affects 1.28 billion adults aged 30–79 years, with two-thirds living in low- and middle-income countries, according to the World Health Organization (WHO). In 2019, the global age-standardised prevalence of hypertension was 34% in men and 32% in women (2). In Tunisia, the Epidemiological Trial of Hypertension in North Africa (ETHNA)-Tunisia study reported a hypertension prevalence of 47.4% among adults in primary care settings, with an age-adjusted rate of 26.9% (3). This suggests that hypertension may be under-diagnosed. Accurate blood pressure (BP) measurement is critical for diagnosing and managing hypertension, preventing adverse drug effects, and avoiding under- or overtreatment. Office blood pressure monitoring (OBPM) has traditionally been the standard method for assessing BP and guiding treatment (4). However, OBPM has limitations that can compromise its reliability, such as white-coat and masked hypertension (5-8). To improve diagnostic accuracy, the European Society of Cardiology (ESC) recommends complementing OBPM with out-of-office measurements obtained in everyday settings, which better reflect an individual's true BP (5). Out-of-office BP monitoring can be done through home blood pressure monitoring (HBPM) or 24-hour ambulatory blood pressure monitoring (ABPM). ABPM records BP at regular intervals over a full day and night, providing a comprehensive BP profile that has proven to be more predictive of cardiovascular outcomes than OBPM (9,10). Consequently, efforts have focused on defining ABPM thresholds equivalent to office BP values to enhance cardiovascular risk stratification. Since 2017, the IDACO collaboration with the American College of Cardiology (ACC) and the American Heart Association (AHA) has proposed ABPM thresholds for each hypertension stage (11,12). Until recently, the ESC and the European Society of Hypertension (ESH) had not adopted stage-specific ABPM thresholds, instead defining only a general hypertension threshold (5). Additionally, ethnic and regional differences have prompted the development of population-specific BP thresholds (12). In 2024, the ESC introduced a new, simplified blood pressure classification, replacing the former grade-based system (optimal, normal, high-normal, and grades 1-3 hypertension) with three categories: non-elevated BP, elevated BP, and hypertension (13). For out-of-office measurement, the 2024 ESC guidelines propose ABPM values corresponding to the non-elevated BP category (<115/65 mmHg for 24-hour, <120/70 mmHg for daytime, and <110/60 mmHg for nighttime ABPM), but they do not propose population-validated ABPM equivalents for the elevated BP or hypertension boundaries themselves (13). Despite progress, ABPM values corresponding to these new categories remain scarcely validated in specific populations, including Tunisians. Given Tunisia's geographical and epidemiological particularities, this study aims to determine ABPM values corresponding to

the elevated BP and hypertension boundaries of the 2024 ESC classification in the Tunisian context, and to provide local reference data.

METHODS

Study design and setting

It was a cross-sectional study on Tunisian adults who were new referrals from the blood bank at Farhat Hached University Hospital in Sousse for confirmation of their blood pressure values from January 2023 to December 2024.

Study population

Any new patient referred from the blood bank at Farhat Hached University Hospital in Sousse for confirmation of their blood pressure values.

Inclusion Criteria

Any patient with no history of HTN and no current use of antihypertensive medication, and older than 18-year-old.

Exclusion Criteria

Any patient diagnosed with white coat hypertension or masked hypertension.

Patients with white-coat or masked hypertension were excluded because these phenotypes are by definition characterized by discordance between office and ambulatory blood pressure, and their inclusion would have introduced analytical noise into the regression/receiver operating characteristic-based calibration used to derive ABPM values corresponding to office blood pressure categories; this exclusion therefore ensured a population with concordant office and ambulatory phenotypes for threshold calibration.

The overall participant flow, including the number of patients assessed, excluded (with reasons), and included in the final analysis, is presented in Figure 1.

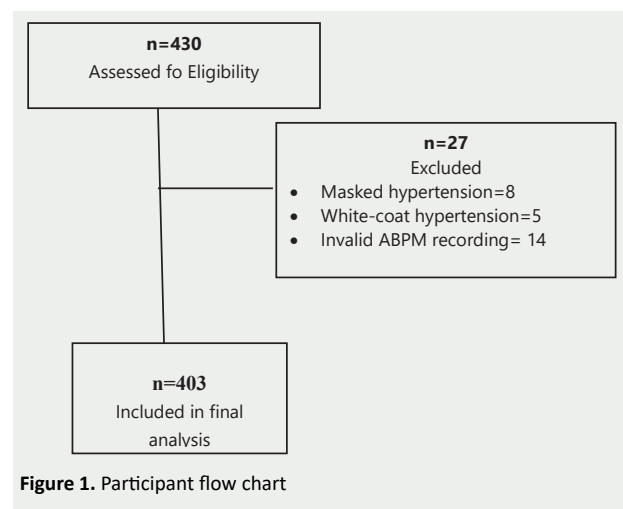


Figure 1. Participant flow chart

Sample Size requirements

The required sample size was calculated using the

formula: $n = [(Z\alpha/2)^2 \times p \times (1-p)] / i^2$. A proportion (p) of confirmed hypertension with home BP measurement (HBPM) and 24h ABPM was 24% (14), a precision of 5%, a risk error (α) of 5% and a loss of 30% due to non-eligible participants being considered, resulting in a required sample size of at least 364 participants.

Data collection

The enrolment and clinical examinations were carried out by one investigator who took both OBPM and ABPM. The physician had to complete the case report form of the registry after patient's interrogation and examination. On physical exam, the physician measured weight, height. The office blood pressure measurements (OBPM) were taken by the blood bank doctor in accordance with ESH recommendations (5) in both upper arms, using a validated conventional oscillometer sphygmomanometer with an appropriate cuff size. All participants were in rest for at least 10 minutes without eating, smoking or exercising prior to the measurement. Measures were taken in a quiet room, in a sitting position, with uncrossed legs, without talking. Three BP measurements were recorded, 5 min apart, and additional measurements only if the first two readings differ by >10 mmHg. BP is recorded as the average of the last two BP readings. Participants were also invited to have their BP assessed by ABPM according to the 2024 ESC recommendations (13). Twenty-four-hour ABPM was performed using a validated and automated oscillometric device, the SunTech Medical Oscar 2 Holter ABPM system (SunTech Medical, Inc., 507 Air Port Blvd, Suite 117, Morrisville, NC, USA), which was set the same day by the scientist from the faculty's cardiology research laboratory. Blood pressure measurements were recorded every 15 minutes during daytime and every 30 minutes during nighttime. Only recordings with at least 20 validated readings during daytime and 7 validating readings during nighttime were included in the study.

Measuring instrument

It included socio-demographic characteristics (age, gender, birth place working status), medical history (smoking habits, history of diabetes, history of high cholesterol) and the biology tests, performed during the last six months before the office visit (fasting glucose, glycated hemoglobin (HbA1c), total cholesterol, HDL-cholesterol, LDL-cholesterol, and triglycerides).

Variables' definitions

-Obesity: was defined as a BMI exceeding 30 Kg/m² and is subclassified into moderate (BMI:30–34.9), morbid (BMI:35– 39.9) and severe (BMI ≥ 40) (15).

-Diabetes: was defined (16) as fasting glucose levels ≥7.0 mmol/L (≥126 mg/dL) in two separate tests or following an oral glucose load equivalent to 75 g glucose, 2 h glucose ≥11.1 mmol/L (≥200 mg/dL) or random glucose ≥11.1 mmol/L (≥200 mg/dL) with the presence of symptoms or glycated hemoglobin HbA1c ≥48 mmol/mol (≥6.5%).

-Dyslipidemia: was defined as (17) total cholesterol (free and esterified) ≥ 2g/l and/or HDL-c <0.4 g/l in men and < 0.5g/l in women and/or triglycerides ≥ 1.5 g/l and/or LDLc < 0.55g/L for secondary prevention or in patients at very high risk, < 0.7g/L in high-risk patients, < 1g/L in patients at moderate risk, < 1.16g/L in low-risk patients.

-Smoking was defined as the act of actively consuming tobacco products (18).

-Hypertension was defined operationally as (5): Conventional Blood office BP; SBP ≥140 mmHg and/or DBP ≥ 90 mmHg, ambulatory BP daytime or awake mean: SBP ≥135 mmHg and/or DBP ≥85, ambulatory BP Nighttime or asleep mean: SBP ≥120 mmHg and/or DBP ≥70 and 24-hour ambulatory BP mean SBP ≥130 mmHg and/or DBP ≥ 80 mmHg.

-Blood pressure was classified operationally according to OBPM as (13), using the 2024 ESC guidelines: non-elevated BP: office SBP <120 mmHg and DBP <70 mmHg; elevated BP: office SBP 120-139 mmHg and/or DBP 70-89 mmHg; hypertension: office SBP ≥140 mmHg and/or DBP ≥90 mmHg.

- The "dipper" status is defined by the European Society of Cardiology as a minimum of 10% decrease in the blood pressure [BP] during the night, it was defined as (5): $100 \times (\text{daytime SBP} - \text{nighttime SBP}) / (\text{daytime SBP})$ for SBP, $100 \times (\text{daytime DBP} - \text{nighttime DBP}) / (\text{daytime DBP})$ for DBP.

-Nocturnal dipping status was classified into four categories according to the dipping rate (5): dipper (≥10% but < 20%), non-dipper (≥0% but < 10%), extreme dipper (≥20%); reverse dipper (<0%).

-Blood pressure measurements were conducted using a validated conventional oscillometer sphygmomanometer after at least 10 minutes of rest. Three measurements were taken 5 minutes apart, with an additional measurement performed if the first two readings differed by more than 10 mmHg; blood pressure was recorded as the average of the last two measurements.

-White-coat hypertension refers to the untreated condition in which BP is elevated in the office, but is normal when measured by ABPM, HBPM, or both (5).

-Masked hypertension refers to untreated patients in whom the BP is normal in the office but is elevated when measured by HBPM or ABPM (5).

-The office based GLOBORISK cardiovascular disease risk score was calculated using age, sex, SBP, current smoking and BMI (19) which was categorized into four groups according to the Tunisian clinical guidelines on hypertension management (19) including low (<10%), moderate (10-19%), high (20-29%) and very high (≥30%).

Ethical considerations

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki (20) and was approved by the Ethical Committee of Faculty of Medicine of Sousse (Committee opinion N278, Ref: CEFMS278/2024). Informed written consent was obtained from all participants. For illiterate participants, informed consent was obtained from their legal guardians. Participants identified during screening with elevated blood pressure or hypertension emergencies

received appropriate treatment.

Statistical analysis

Data entry and analysis were carried out using the SPSS 23.0 (SPSS, Chicago, IL, USA) statistical package. Continuous variables were presented as means $\pm$ standard deviation in case of Gaussian distribution. The receiver operator characteristics analysis was used to compare the area under the curve (AUC) to determine the ABPM value corresponding to the elevated blood pressure and hypertension boundaries of the 2024 ESC classification, relative to OBPM. Optimal cut-off values were defined as the point maximizing the Youden index (sensitivity + specificity - 1); corresponding sensitivity, specificity, and 95% confidence intervals for the AUC are reported for each threshold. Coefficient of correlation was used. In order to classify participants according to the 2024 ESC blood pressure categories based on data from ABPM, we first investigated the relationship between office blood pressure (OBPM) and the average daytime (awake) blood pressure. Pearson correlation analysis was used between office systolic blood pressure and average daytime systolic blood pressure, office diastolic blood pressure and average daytime diastolic blood pressure. Scatter plots were used to visualize the relationship between office measurements and those taken during the awake period. To assess the agreement between OBPM and ABPMs during the awake period, we used the Bland-Altman method. This approach evaluates the agreement between two quantitative methods by plotting the mean difference of the measurements versus their mean, allowing calculation of the mean bias and the 95% limits of agreement (mean bias $\pm$ 1.96 SD).

RESULTS

Baseline characteristics of the study population

A total of 430 subjects were initially screened, of whom 403 were deemed eligible. The final sample included 274 males (68%) and 129 females (32%), with a mean age of 49.01 ± 12.44 years. The average body mass index (BMI) was 29.02 ± 4.01 , with 156 participants (38.7%) classified as obese. A total of 143 participants were identified as active smokers, and 58 (14.8%) had confirmed diabetes. The majority of participants ($n = 372$; 92.3%) had abnormal lipid levels, while 39 (9.7%) were classified as having a very high cardiovascular risk. According to OBPM, classified using the 2024 ESC categories, 26 participants (6.5%) had non-elevated blood pressure, 144 (35.7%) had elevated blood pressure, and 233 (57.8%) had hypertension (Table 1).

Descriptive study

In individuals with non-elevated blood pressure, the mean office systolic/diastolic BP was 109.8 ± 9.9 mmHg and 58.7 ± 7.5 mmHg, with 24-hour averages of 112.2 ± 10.2 mmHg and 61.7 ± 5.3 mmHg. During awake hours,

the average systolic/diastolic BP was 114.2 ± 10.4 mmHg and 64.2 ± 7.0 mmHg, while nighttime averages were 107.6 ± 13.2 mmHg and 56.4 ± 6.7 mmHg. In individuals with elevated blood pressure, the mean office systolic/diastolic BP was 129.4 ± 6.6 mmHg and 77.0 ± 7.9 mmHg, with 24-hour averages of 125.2 ± 9.9 mmHg and 72.6 ± 8.4 mmHg. Awake average systolic/diastolic BP was 128.1 ± 9.8 mmHg and 74.8 ± 9.1 mmHg, while nighttime averages were 114.9 ± 16.6 mmHg and 64.8 ± 10.8 mmHg. In individuals with hypertension, the mean office systolic/diastolic BP was 150.0 ± 12.0 mmHg and 91.3 ± 9.9 mmHg, with 24-hour averages of 138.4 ± 13.2 mmHg and 81.3 ± 9.3 mmHg. Awake averages were 142.4 ± 12.8 mmHg and 84.6 ± 9.4 mmHg, while nighttime averages were 123.9 ± 15.4 mmHg and 70.3 ± 10.1 mmHg (Table 2).

Table 1. Baseline characteristics in participants

Variables		N (%)
Gender	Male	274 (68.0)
	Female	129 (32.0)
Age $m \pm ET$		49.01 ± 12.44
Age ≥ 40		292 (72.8)
Smoking		143 (35.3)
Diabetes		58 (14.8)
Dyslipidemia		372 (92.3)
Obesity		156 (38.7)
BMI		29.02 ± 4.01
Blood pressure category (2024 ESC)	Non-elevated	26 (6.5)
	Elevated	144 (35.7)
	Hypertension	233 (57.8)
Global Risk score	Low cardiovascular risk	79 (19.6)
	Moderate cardiovascular risk	96 (23.8)
	High cardiovascular risk	68 (16.9)
	Very High cardiovascular risk	39 (9.7)

Analytical study

For the elevated BP boundary, the corresponding ABPM values — rounded to the nearest whole mmHg for clinical applicability (see Table 3 for exact statistically-derived values) — are 121/67 mm Hg (24-hour), 125/71 mm Hg (daytime), and 112/65 mm Hg (nighttime). For the hypertension boundary, the corresponding ABPM values are 128/73 mm Hg (24-hour), 131/73 mm Hg (daytime), and 112/66 mm Hg (nighttime) (Table 3). For the elevated BP boundary, diagnostic performance was excellent for 24-hour and daytime measurements (AUC 0.907 to 0.928), and good for nighttime measurements (AUC 0.753 to 0.827) (Figure 2). For the hypertension boundary, diagnostic performance was good, with AUCs ranging from 0.793 to 0.846 for 24-hour and daytime measurements, and 0.689 to 0.694 for nighttime measurements (Figure 3). Sensitivity, specificity, and the 95% confidence interval of the AUC for each boundary are reported in Table 4.

Table 2. Mean Blood Pressure Values measured by OBPM and ABPM Across Different Blood Pressure Categories

Variable	Mean values of BP according to OBPM and ABPM in non-elevated blood pressure	Mean values of BP according to OBPM and ABPM in elevated BP	Mean values of BP according to OBPM and ABPM in hypertension
Office systolic BP	109.8 ± 9.9 mmHg	129.4 ± 6.6 mmHg	150.0 ± 12.0 mmHg
Office diastolic BP	58.7 ± 7.5 mmHg	77.0 ± 7.9 mmHg	91.3 ± 9.9 mmHg
24h average systolic BP	112.2 ± 10.2 mmHg	125.2 ± 9.9 mmHg	138.4 ± 13.2 mmHg
24h average diastolic BP	61.7 ± 5.3 mmHg	72.6 ± 8.4 mmHg	81.3 ± 9.3 mmHg
Awake average systolic BP	114.2 ± 10.4 mmHg	128.1 ± 9.8 mmHg	142.4 ± 12.8 mmHg
Awake average diastolic BP	64.2 ± 7.0 mmHg	74.8 ± 9.1 mmHg	84.6 ± 9.4 mmHg
Nighttime average systolic BP	107.6 ± 13.2 mmHg	114.9 ± 16.6 mmHg	123.9 ± 15.4 mmHg
Nighttime average diastolic BP	56.4 ± 6.7 mmHg	64.8 ± 10.8 mmHg	70.3 ± 10.1 mmHg

Table 3. Proposals for Ambulatory Blood Pressure Thresholds

	OBP	24H	Day	Night
Elevated BP boundary, mm Hg	120/70	121/67	125/71	112/65
Hypertension boundary, mm Hg	140/90	128/73	131/73	112/66

ABPM values are rounded to the nearest whole mmHg for clinical applicability. The underlying statistically-derived optimal cut-offs (Youden index, based on the midpoint between consecutive observed values) carried 0.5 mmHg precision; exact values are available from the authors on request.

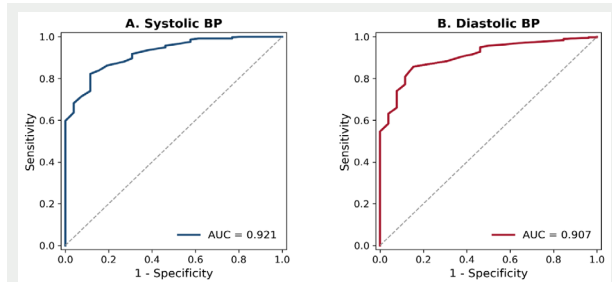


Figure 2. ROC Curves for systolic and diastolic OBP and awake average BP for the elevated BP boundary

Table 4. Diagnostic performance (sensitivity, specificity, AUC with 95% confidence interval) of ABPM values for the elevated BP and hypertension boundaries of the 2024 ESC classification, using the corresponding office blood pressure boundary as reference

Boundary	Period	Parameter	ABPM cut-off, mmHg	Sensitivity	Specificity	AUC (95% CI)
Elevated BP	24-hour	Systolic	121	83.0%	84.6%	0.908 (0.855-0.961)
	24-hour	Diastolic	67	88.6%	88.5%	0.928 (0.895-0.961)
	Daytime	Systolic	125	82.2%	88.5%	0.921 (0.879-0.964)
	Daytime	Diastolic	71	85.7%	84.6%	0.907 (0.861-0.952)
	Nighttime	Systolic	112	69.5%	73.1%	0.753 (0.646-0.861)
	Nighttime	Diastolic	65	61.5%	92.3%	0.827 (0.764-0.890)
Hypertension	24-hour	Systolic	128	84.5%	68.2%	0.829 (0.788-0.869)
	24-hour	Diastolic	73	82.4%	61.2%	0.793 (0.749-0.837)
	Daytime	Systolic	131	87.1%	67.6%	0.846 (0.808-0.884)
	Daytime	Diastolic	73	91.4%	52.4%	0.803 (0.761-0.846)
	Nighttime	Systolic	112	79.0%	50.0%	0.689 (0.636-0.741)
	Nighttime	Diastolic	66	67.4%	64.1%	0.694 (0.642-0.747)

OBPM, office blood pressure monitoring; ABPM, ambulatory blood pressure monitoring; AUC, area under the ROC curve; CI, confidence interval. For the elevated BP boundary, cases were participants with elevated BP or hypertension (office BP ≥120/70 mmHg) and controls were participants with non-elevated BP. For the hypertension boundary, cases were participants with hypertension (office BP ≥140/90 mmHg) and controls were participants with non-elevated or elevated BP. Sensitivity and specificity are reported at the ABPM cut-off value shown in Table 3. AUC 95% CIs were computed using the DeLong method.

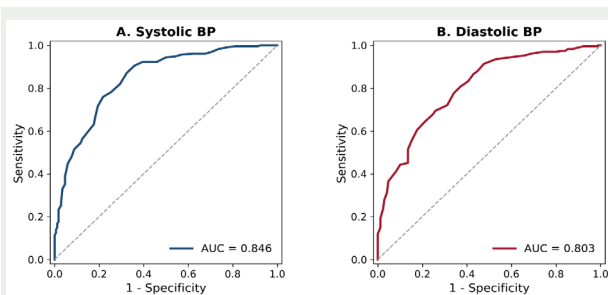
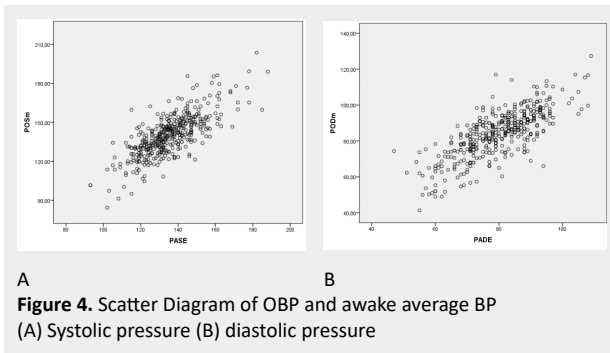


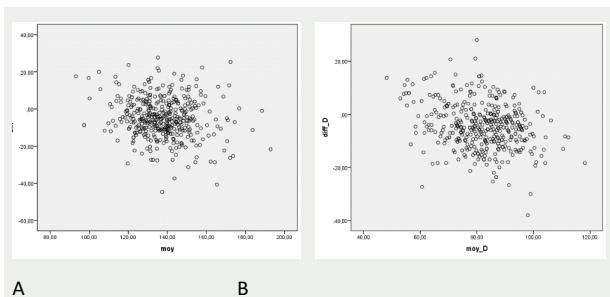
Figure 3. ROC Curves for systolic and diastolic OBP and awake average BP for the hypertension boundary

In order to classify our population into the 2024 ESC blood pressure categories according to ABPM data, there was correlation between office systolic pressure and day time average systolic pressure (Correlation coefficient=0.755), and the same relationship was observed between office diastolic pressure and day time average diastolic pressure (Correlation coefficient=0.756) with $p < 0.001$. The scatter plot indicates that there was a positive correlation between office systolic pressure and awake average systolic pressure, and the degree of fitting was high (Figure 4A).

There was a positive correlation between office diastolic pressure and awake average diastolic pressure, and the degree of fitting was also high (Figure 4B).



The Bland Altman plot showed that office systolic pressure and awake average systolic pressure were consistent ($p=0.012$, Figure 5A), as were office diastolic pressure and awake average diastolic pressure ($p<0.001$, Figure 5B). The mean bias (awake ABPM minus OBPM) was -4.6 mmHg for systolic pressure (95% CI -5.7 to -3.6) with 95% limits of agreement of -25.6 to +16.3 mmHg, and -4.3 mmHg for diastolic pressure (95% CI -5.1 to -3.5) with 95% limits of agreement of -21.2 to +12.6 mmHg. These findings indicate that awake ABPM values were, on average, slightly lower than OBPM values, with a moderate spread of individual differences that should be taken into account when using OBPM-derived thresholds to infer ABPM values at the individual level.



DISCUSSION

OBPM alone may lack sufficient diagnostic accuracy, especially near diagnostic thresholds. Ambulatory blood pressure monitoring (ABPM) offers several advantages, including detection of nocturnal hypertension and exertional or transient hypotension, as emphasized in the 2024 ESC guidelines (13). Despite its clinical value, ABPM remains underutilized in low-resource settings due to cost and limited availability.

Initial ABPM thresholds emerged in the 1990s from studies like O'Brien et al. (21), though earlier targets were higher than current recommendations. Subsequent research, including that by Cox (22), confirmed ABPM and home blood pressure monitoring (HBPM) as more predictive of cardiovascular outcomes than OBPM. The 2017 American Heart Association (AHA) guidelines (23) were among the first to align ABPM values with

specific OBPM thresholds (e.g., OBPM 130/70 mmHg $\approx$ 125/75 mmHg 24h ABPM). However, these lacked equivalents for lower OBPM levels, and the 2024 ESC guidelines (13) now favor a simplified classification: non-elevated BP, elevated BP, or hypertension. Specifically, the 2024 ESC guidelines define non-elevated office BP as $<120/70$ mmHg, elevated office BP as 120-139/70-89 mmHg, and hypertension as $\geq 140/90$ mmHg; for out-of-office measurement, non-elevated ABPM is defined as $<115/65$ mmHg (24-hour), $<120/70$ mmHg (daytime), and $<110/60$ mmHg (nighttime), while no grade-specific ABPM equivalents are proposed for the elevated BP or hypertension boundaries themselves (13). Our locally derived ABPM value for the elevated BP boundary (121/67 mmHg 24-hour, 125/71 mmHg daytime, 112/65 mmHg nighttime) was closely consistent with the ESC 2024 reference values for non-elevated ABPM, supporting the applicability of the guideline's out-of-office thresholds in a Tunisian population. In contrast, the ABPM value we identified for the hypertension boundary (128/73 mmHg 24-hour, 131/73 mmHg daytime) was somewhat lower than the ABPM value classically used in international guidelines to confirm hypertension (approximately 130/80 mmHg 24-hour), particularly for diastolic pressure. This discrepancy may reflect the relatively young, predominantly male composition of our sample, population-specific factors relevant to the Tunisian and North African context, or the limited size of some subgroups, and warrants confirmation in larger, more diverse local cohorts before it is used to adjust diagnostic thresholds in clinical practice.

Our findings confirm a greater discrepancy between OBPM and ABPM in hypertensive vs. non-hypertensive individuals, likely due to stress-induced sympathetic activation during clinical assessment. The ABPM value identified for the elevated BP boundary is broadly consistent with the out-of-office thresholds reported by Lowandowska et al. and Head et al. (24,25), while the value corresponding to the hypertension boundary was somewhat lower, possibly reflecting the younger, predominantly male composition of our sample.

These results are particularly relevant for the MENA region, which faces demographic aging and a rising burden of non-communicable diseases (26,27). Simultaneously, the region is facing a surge in non-communicable diseases due to shifts in diet, increased tobacco use, physical inactivity, and urbanization (28,29). In Tunisia, the ETHNA study reported a 47.4% prevalence of hypertension in adults (3), underlining the need for precise BP assessment. Given the continuous and linear relationship between blood pressure levels and cardiovascular disease risk, even modest elevations in BP are associated with significant morbidity and mortality (30,31). The SPRINT trial showed that targeting a systolic BP below 120 mmHg significantly reduced all-cause mortality compared to a target of 140 mmHg (32), and Canoy et al. confirmed that lowering systolic BP by only 5 mmHg reduces the risk of major cardiovascular events by approximately 10% (33).

These findings underscore the critical need for accurate,

reproducible BP measurements in both clinical and population health contexts. Unfortunately, OBPM remains the most commonly used method worldwide despite its limitations in accuracy and reproducibility (34,35). These limitations have prompted the adoption of newer techniques, such as unattended automated office blood pressure (AOBP) measurement, to mitigate white-coat effects and observer bias (36).

In this regard, ABPM has emerged as the most robust and predictive method for BP assessment. It provides a full 24-hour profile, detects nocturnal hypertension, and identifies "non-dipping" patterns, which are strong predictors of cardiovascular and renal events (37,38). Furthermore, ABPM has demonstrated superior prognostic value over both OBPM and HBPM in multiple comparative studies (39,40).

Our findings reinforce the diagnostic value of ABPM, particularly in Tunisia, where OBPM-based misclassification may lead to over- or under-treatment. This is especially relevant in resource-limited settings, where diagnostic precision helps reduce costs and cardiovascular risk. Ethnic differences influence BP variability: African Americans show higher diastolic BP, East Asians higher systolic BP, while our Mediterranean Tunisian sample showed intermediate patterns. Dietary habits and socioeconomic status may also affect BP thresholds. Because our sample was restricted to treatment-naïve individuals, our findings are not confounded by antihypertensive drug effects, although this restriction also limits their direct generalizability to patients already receiving treatment, who represent a substantial proportion of real-world hypertensive populations.

Methodological variability also matters: our regression-based approach reflects clinical practice, unlike outcome-based methods such as Cheng et al. (2019) and Wei Gao et al. (41). ABPM thresholds should be population-specific. Given Tunisia's demographic and cultural similarities with other North African countries, these thresholds may be hypothesis-generating for the region; however, in the absence of external validation in other North African populations, this extrapolation remains speculative and should be confirmed by dedicated multicentre studies before any regional application. Future studies should explore ethnic, economic, and therapeutic factors while promoting standardization to enhance comparability.

Strengths and limitations of the study

One of the main strengths of this study is its originality and contextual relevance: It is the first study in Tunisia to determine ABPM values corresponding to the 2024 ESC blood pressure categories. This addresses a notable gap, as most thresholds are based on data from high-income countries with different demographic and lifestyle characteristics. By focusing on a Tunisian sample with traits shared across North Africa, these values may be a useful starting point for the region, pending external validation in other Maghreb populations.

Another key strength lies in the pragmatic and restrictive participant selection: by including only treatment-naïve

individuals, the study avoided the confounding effect of antihypertensive drugs on blood pressure readings, allowing a clearer characterization of the intrinsic relationship between office and ambulatory blood pressure.

The relatively young, predominantly male cohort also contrasts with older, more gender-balanced international samples.

Patients with white-coat or masked hypertension were deliberately excluded in order to derive ABPM correspondence values in a population with concordant office and ambulatory blood pressure phenotypes, thereby limiting analytical noise in the regression/ROC-based calibration. However, as these phenotypes represent a major clinical indication for ABPM, this exclusion may introduce a selection bias and limits the direct extrapolation of our thresholds to the broader hypertensive population, including patients with white-coat or masked hypertension. Further studies incorporating these phenotypes are needed to confirm the applicability of these thresholds in unselected populations.

Methodologically, the use of a regression-based approach aligns with clinical practice: It allows for immediate interpretation by linking ABPM values to office BP categories. Strict adherence to ESC recommendations and standardized measurements by trained physicians enhance the study's rigor.

Data reliability is also a strength: All measurements were performed under standardized conditions using validated equipment, reducing variability and increasing precision. Nevertheless, several limitations must be acknowledged: Participants were recruited from clinical settings, which may not reflect the broader population. The cross-sectional design limits causal inference. Moreover, widespread ABPM use is challenged by device availability, cost, and provider training needs. The non-elevated BP subgroup was relatively small ($n=26/403$, 6.5%), which limits the statistical robustness and precision of the corresponding ABPM value; this estimate should therefore be considered exploratory and interpreted with caution until confirmed in larger, more balanced samples. Second, the cross-sectional design of the study inherently limits its capacity to establish causal relationships or predict future cardiovascular outcomes. While the regression-based approach is useful for generating diagnostic thresholds, it does not account for the longitudinal risk associated with various BP levels. Studies employing outcome-based designs could complement these findings by linking ABPM thresholds to long-term morbidity and mortality.

Finally, the broader implementation of ABPM in Tunisia and the Maghreb is constrained by practical challenges, including device availability, cost, and the need for healthcare provider training in both technical operation and interpretation of results. These barriers may hinder the routine use of ABPM in primary care settings, despite its well-documented diagnostic superiority.

In summary, while the study has limitations typical of observational cross-sectional research, it offers novel and

clinically valuable insight into hypertension classification using ABPM in a North African population. The thresholds identified here lay the groundwork for future prospective research and may inform updates to regional and national hypertension management guidelines.

CONCLUSION

This study provides, to our knowledge, the first ABPM values corresponding to the 2024 ESC blood pressure categories in a Tunisian population, contributing local data to a field where population-specific reference values remain scarce in North Africa. The value identified for the elevated BP boundary was closely consistent with the ESC 2024 reference values, supporting their applicability in this population, while the value corresponding to the hypertension boundary was somewhat lower and warrants further investigation. These findings provide observational data on the relationship between office and ambulatory blood pressure measurements in this population, and any broader use for regional guidance or comparison with other Maghreb countries would require external validation. Further research should explore longitudinal outcomes and standardize measurement protocols across diverse populations.

REFERENCES

- Cardiovascular diseases (CVDs) [Internet]. [cited 2025 Mar 19]. Available from: <https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-cvds>
- Hypertension [Internet]. [cited 2025 Mar 19]. Available from: <https://www.who.int/news-room/fact-sheets/detail/hypertension>
- Boujnah R, Nazek L, Maalej M, Achhab YE, Nejari C. Hypertension in Tunisian adults attending primary care physicians (ETHNA-Tunisia). *Indian Heart J.* 2018;70(4):544–7.
- Noh SA, Kim HS, Kang SH, Yoon CH, Youn TJ, Chae IH. History and evolution of blood pressure measurement. *Clin Hypertens.* 2024 Apr 1;30(1):9.
- Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, et al. 2018 ESC/ESH Guidelines for the management of arterial hypertension. *Eur Heart J.* 2018 Sep 1;39(33):3021–104.
- Whelton PK, Carey RM, Aronow WS, Casey DE, Collins KJ, Dennison Himmelfarb C, 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. *Hypertension.* 2018 Jun;71(6):e13–115.
- Muntner P, Shimbo D, Carey RM, Charleston JB, Gaillard T, Misra S, et al. Measurement of Blood Pressure in Humans: A Scientific Statement From the American Heart Association. *Hypertension.* 2019 May;73(5):e35–66.
- Kallioinen N, Hill A, Horswill MS, Ward HE, Watson MO. Sources of inaccuracy in the measurement of adult patients' resting blood pressure in clinical settings: a systematic review. *J Hypertens.* 2017 Mar;35(3):421–41.
- January 2025 - Volume 43 - Issue 1 : Journal of Hypertension [Internet]. [cited 2025 Mar 19]. Available from: <https://journals.lww.com/jhypertension/toc/2025/01000>
- Yang WY, Melgarejo JD, Thijs L, Zhang ZY, Boggia J, Wei FF, et al. Association of Office and Ambulatory Blood Pressure With Mortality and Cardiovascular Outcomes. *JAMA.* 2019 Aug 6;322(5):409–20.
- Poudel B, Booth JN, Sakhuja S, Moran AE, Schwartz JE, Lloyd-Jones DM, et al. Prevalence of ambulatory blood pressure phenotypes using the 2017 American College of Cardiology/American Heart Association blood pressure guideline thresholds: data from the Coronary Artery Risk Development in Young Adults study. *J Hypertens.* 2019 Jul;37(7):1401–10.
- Huang QF, Yang WY, Asayama K, Zhang ZY, Thijs L, Li Y, et al. Ambulatory Blood Pressure Monitoring to Diagnose and Manage Hypertension. *Hypertension.* 2021 Feb;77(2):254–64.
- McEvoy JW, McCarthy CP, Bruno RM, Brouwers S, Canavan MD, Ceconi C, Christodorescu RM, Daskalopoulou SS, Ferro CJ, Gerdtts E, et al.; ESC Scientific Document Group. 2024 ESC Guidelines for the management of elevated blood pressure and hypertension. *Eur Heart J.* 2024 Oct 7;45(38):3912–4018.
- Radovanovic D, Muggli F, Bianchetti M, Gallino A, Parati G, Suter PM, et al. Comparison of office, home and ambulatory blood pressure measurements in hypertensive and suspected hypertensive SWICOS participants. *Blood Pressure.* 2023 Dec 31;32(1):2234496.
- Nuttall FQ. Body Mass Index: Obesity, BMI, and Health: A Critical Review. *Nutr Today.* 2015 May;50(3):117–28.
- Marx N, Federici M, Schütt K, Müller-Wieland D, Ajjan RA, Antunes MJ, et al. 2023 ESC Guidelines for the management of cardiovascular disease in patients with diabetes. *Eur Heart J.* 2023 Oct 14;44(39):4043–140.
- Mach F, Baigent C, Catapano AL, Koskinas KC, Casula M, Badimon L, et al. 2019 ESC/EAS Guidelines for the management of dyslipidaemias: lipid modification to reduce cardiovascular risk. *Eur Heart J.* 2020 Jan 1;41(1):111–88.
- West R. Tobacco smoking: Health impact, prevalence, correlates and interventions. *Psychol Health.* 2017 Aug;32(8):1018–36.
- Hajifathalian K, Ueda P, Lu Y, Woodward M, Ahmadvand A, Aguilar-Salinas CA, et al. A novel risk score to predict cardiovascular disease risk in national populations (Globorisk): a pooled analysis of prospective cohorts and health examination surveys. *Lancet Diabetes Endocrinol.* 2015 May;3(5):339–55.
- WMA - The World Medical Association-WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Participants [Internet]. [cited 2025 Mar 19]. Available from: <https://www.wma.net/policies-post/wma-declaration-of-helsinki/>
- O'Brien E, Murphy J, Tyndall A, Atkins N, Mee F, McCarthy G, et al. Twenty-four-hour ambulatory blood pressure in men and women aged 17 to 80 years: the Allied Irish Bank Study. *Journal of Hypertension.* 1991 Apr;9(4):355–60.
- Cox J, O'Malley K, Atkins N, O'Brien E. A comparison of the twenty-four-hour blood pressure profile in normotensive and hypertensive subjects. *Journal of hypertension Supplement : official journal of the International Society of Hypertension.* 1991 Feb 1;9:S3–6.
- Muntner P, Carey RM, Jamerson K, Wright JT, Whelton PK. Rationale for Ambulatory and Home Blood Pressure Monitoring Thresholds in the 2017 American College of Cardiology/American Heart Association Guideline. *Hypertension.* 2019 Jan;73(1):33–8.
- Lewandowska K, Wasiliew S, Kukfisz A, Hofman M, Woźniak P, Radziemski A, et al. Target Blood Pressure Values in Ambulatory Blood Pressure Monitoring. *High Blood Press Cardiovasc Prev.* 2023 Jan;30(1):29–36.
- Head GA, Mihailidou AS, Duggan KA, Beilin LJ, Berry N, Brown MA, et al. Definition of ambulatory blood pressure targets for diagnosis and treatment of hypertension in relation to clinic blood pressure: prospective cohort study. *BMJ.* 2010 Apr 14;340:c1104.
- Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, et al. Global Burden of Cardiovascular Diseases and Risk Factors, 1990–2019: Update From the GBD 2019 Study. *J Am Coll Cardiol.* 2020 Dec 22;76(25):2982–3021.
- Population change in Europe, the Middle-East and North Africa: beyond the demographic divide. First issued in paperback. London: Routledge; 2018. (International population studies).
- Aggarwal A, Patel P, Lewison G, Ekzayez A, Coutts A, Fouad FM, et al. The Profile of Non-Communicable Disease (NCD) research in the Middle East and North Africa (MENA) region: Analyzing the NCD burden, research outputs and international research collaboration. *PLoS One.* 2020;15(4):e0232077.
- Balouchi A, Rafsanjani MHAP, Al-Mutawaa K, Naderifar M, Rafiemanesh H, Ebadi A, et al. Hypertension and Pre-Hypertension

- in Middle East and North Africa (MENA): A Meta-Analysis of Prevalence, Awareness, Treatment, and Control. *Curr Probl Cardiol*. 2022 Jul;47(7):101069.
30. Zheng R, Xu Y, Li M, Lu J, Wu S, Niu J, et al. Examining the Linear Association Between Blood Pressure Levels and Cardiovascular Diseases in the Absence of Major Risk Factors in China. *Circ Cardiovasc Qual Outcomes*. 2022 Sep;15(9):e008774.
 31. Malik R, Georgakis MK, Vujkovic M, Damrauer SM, Elliott P, Karhunen V, et al. Relationship Between Blood Pressure and Incident Cardiovascular Disease: Linear and Nonlinear Mendelian Randomization Analyses. *Hypertension*. 2021 Jun;77(6):2004–13.
 32. SPRINT Research Group, Wright JT, Williamson JD, Whelton PK, Snyder JK, Sink KM, et al. A Randomized Trial of Intensive versus Standard Blood-Pressure Control. *N Engl J Med*. 2015 Nov 26;373(22):2103–16.
 33. Canoy D, Nazarzadeh M, Copland E, Bidel Z, Rao S, Li Y, et al. How Much Lowering of Blood Pressure Is Required to Prevent Cardiovascular Disease in Patients With and Without Previous Cardiovascular Disease? *Curr Cardiol Rep*. 2022 Jul;24(7):851–60.
 34. Voorbrood VMI, de Schepper EIT, Bohnen AM, Ruitkamp MFE, Rijnbeek PR, Bindels PJE. Blood pressure measurements for diagnosing hypertension in primary care: room for improvement. *BMC Prim Care*. 2024 Jan 2;25(1):6.
 35. Vischer AS, Burkard T. How Should We Measure and Deal with Office Blood Pressure in 2021? *Diagnostics (Basel)*. 2021 Feb 3;11(2):235.
 36. Doane J, Flynn M, Archibald M, Ramirez D, Conroy MB, Stults B. Unattended automated office blood pressure measurement: Time efficiency and barriers to implementation/utilization. *J Clin Hypertens (Greenwich)*. 2020 Apr;22(4):598–604.
 37. Turner JR, Viera AJ, Shimbo D. Ambulatory blood pressure monitoring in clinical practice: a review. *Am J Med*. 2015 Jan;128(1):14–20.
 38. Salles GF, Reboldi G, Fagard RH, Cardoso CRL, Pierdomenico SD, Verdecchia P, et al. Prognostic Effect of the Nocturnal Blood Pressure Fall in Hypertensive Patients: The Ambulatory Blood Pressure Collaboration in Patients With Hypertension (ABC-H) Meta-Analysis. *Hypertension*. 2016 Apr;67(4):693–700.
 39. Peeters LEJ, van Oortmerssen JAE, Derks LH, den Hertog H, Fonville S, Verboon C, et al. Comparison of automated office blood pressure measurement with 24-hour ambulatory blood pressure measurement. *Blood Press*. 2022 Dec;31(1):9–18.
 40. Verdecchia P, Clement D, Fagard R, Palatini P, Parati G. Blood Pressure Monitoring. Task force III: Target-organ damage, morbidity and mortality. *Blood Press Monit*. 1999 Dec;4(6):303–17.
 41. Gao W, Jin Y, Bao T, Huang Y. Comparison of ambulatory blood pressure monitoring and office blood pressure in primary health care of populations at a high risk of hypertension. *Front Public Health [Internet]*. 2023 Jan 11 [cited 2025 Mar 21];10. Available from: <https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2022.985730/full>