



# IMPACT OF OBESITY AND INSULIN RESISTANCE ON BLOOD PRESSURE VARIABILITY IN YOUNG MILITARY PERSONNEL AND THEIR ROLE IN REDUCED OCCUPATIONAL PERFORMANCE

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## Abstract:

Rising obesity and insulin resistance in young adults threaten long-term cardiovascular health. We examined how these metabolic factors relate to 24-hour blood pressure variability (BPV) and occupational performance in 180 healthy young soldiers (mean age 22 years). Participants underwent clinical assessment (BMI, waist circumference), 24-h ambulatory BP monitoring (ABPM) including mean daytime/nighttime BP, dipping status, morning surge and BP variability indices, and laboratory testing (lipid profile, fasting glucose, insulin for HOMA-IR, HbA1c, cortisol, vitamin D, magnesium, liver enzymes, CBC). We also recorded 12-lead ECG and echocardiography, and collected functional performance data (physical fitness tests, service readiness measures). Overweight/obese subjects (n=60) had significantly higher HOMA-IR and dyslipidemia than controls (all  $p < 0.01$ ). ABPM showed that risk subjects had blunted nocturnal dipping (<10% BP reduction) and 40% higher systolic BP standard deviation. HOMA-IR positively correlated with 24-h systolic BP variability ( $r \approx 0.30$ ,  $p < 0.01$ ). Elevated cortisol and low vitamin D/magnesium were common in the risk group, and each was associated with greater BPV. Early echocardiographic signs (mild LV diastolic relaxation impairment) were more frequent in the metabolic risk group. Importantly, higher BPV and IR were linked to lower scores on military physical fitness tests. These findings indicate that even subclinical obesity and IR disrupt circadian BP control and are associated with decrements in work capacity. Routine early screening of young soldiers with ABPM and metabolic markers, followed by targeted lifestyle and nutritional interventions (weight management, exercise, vitamin D/magnesium supplementation), is recommended to mitigate future cardiovascular risk and preserve operational readiness.

## Keywords:

## INTRODUCTION

Young adult military cohorts are not immune to the “premature aging” of cardiovascular risk; in fact, the prevalence of obesity, insulin resistance (IR), and metabolic syndrome is rising even in ostensibly healthy service members. This trend is worrisome because cardiovascular disease (CVD) risk factors emerging in youth often remain silent until mature. In the military context, maintaining fitness and combat readiness is critical, and metabolic disturbances can undermine physical performance and increase health-related attrition. Emerging evidence suggests that **blood pressure variability (BPV)** – fluctuations of BP over hours to days – carries independent prognostic value beyond average BP. Elevated BPV has been linked to

stroke, myocardial damage, renal decline, and mortality, even when mean BP is normal. In particular, increased daytime–nighttime BP variability and blunted nocturnal dip (non-dipping profile) are associated with insulin resistance and components of the metabolic syndrome.

Obesity (especially central obesity) and IR trigger physiologic changes – sympathetic overactivity, renin–angiotensin–aldosterone system (RAAS) activation, endothelial dysfunction, and sodium retention – that not only elevate BP level but also amplify its instability over 24 hours. For example, early IR can raise circulating aldosterone and cortisol levels, thereby increasing BP and disrupting normal circadian regulation. Indeed, a study of hypertensive adults found



that higher late-night salivary cortisol and aldosterone correlated with increased ambulatory BP, alongside insulin resistance and central obesity. Likewise, non-dipping ABPM profiles – defined as <10% nocturnal BP fall – have been independently linked to glucose intolerance, dyslipidemia and metabolic syndrome in normotensive adults. Collectively, such findings imply that metabolic risk factors may drive early vascular dysregulation before frank hypertension or clinical CVD appear.

In military populations, these issues are magnified by duty-related stress and lifestyle factors. Recent reviews note that military personnel, like civilians, are showing earlier onset of coronary risk factors; in fact, more than half of soldiers may be overweight or obese, and high training loads combined with erratic sleep/eating create metabolic stress. Thus, monitoring for subtle cardiovascular dysfunction is strategically important. Ambulatory blood pressure monitoring (ABPM) – tracking 24h BP, dip status, morning surge, and BPV – provides a window into early endothelial and autonomic changes that clinic BP cannot detect. Increased BPV on ABPM could serve as an **early warning marker** of vascular compromise.

Given this context, we hypothesized that obesity and IR in young soldiers would be associated with greater 24-h BP variability and impaired performance, independent of average BP. This study therefore aimed to *comprehensively* evaluate the impact of metabolic factors on BPV and to link these findings to operational capacity. We measured anthropometrics, HOMA-IR, lipid/glucose/cortisol/other labs, 24-h ABPM (mean BP, dip, variability), ECG/echo, and functional fitness in young military personnel. Our goals were to determine how obesity and IR affect BP circadian rhythms and to assess whether these factors predict reduced physical service readiness. The ultimate objective was to inform early screening and targeted preventive strategies in military health management.

## **METHODS**

### **Study Population**

This cross-sectional observational study included **180 male soldiers**, age 18–25, recruited from the Armed Forces Central Clinic and local military units. **Case group:** 100 volunteers with overweight/obesity (BMI $\geq$ 25) or biochemical insulin resistance (HOMA-IR above 75th percentile for age) based on initial screening. **Control group:** 80 age- and duty-matched soldiers with normal BMI and metabolic profiles (no signs of metabolic syndrome). Exclusion criteria were known hypertension, diabetes, cardiovascular disease, endocrine disorders, and use of BP-altering medications. All participants provided

informed consent. The study was approved by the institutional ethics committee.

### *Clinical and Anthropometric Assessment*

Each subject underwent a standardized clinical evaluation. **Anthropometry** included weight, height, BMI (kg/m<sup>2</sup>), waist circumference, and body fat percentage (via bioimpedance). Overweight and obesity were graded by WHO criteria. IR was preliminarily screened by fasting insulin and glucose; **HOMA-IR** was calculated as (fasting insulin [ $\mu$ U/mL]  $\times$  fasting glucose [mmol/L]) / 22.5. A HOMA-IR above a validated cutoff (typically  $\approx$ 2.5–3 for young adults) indicated insulin resistance. Waist-to-hip ratio was noted for central adiposity.

### *Blood Pressure Monitoring*

Participants underwent **24-hour ABPM** using validated oscillometric devices on a routine working day. BP was recorded every 20–30 minutes during the day and every 30–60 minutes at night. From ABPM we derived: mean 24-h, daytime, and nighttime SBP and DBP; night/day BP ratio; nocturnal “dipping” status (normal  $\geq$ 10% drop in nocturnal SBP) vs non-dipper (<10%). BP variability indices were computed: standard deviation (SD) of 24h SBP and DBP, and coefficient of variation. Morning surge (difference between mean morning BP and nocturnal trough) was also calculated. Non-dipping pattern and increased SD are markers of impaired circadian regulation.

### **Laboratory Measurements**

Fasting blood samples were taken for: **glucose, insulin (to compute HOMA-IR), HbA1c** (reflecting glycemic control), **lipid profile** (total cholesterol, LDL, HDL, triglycerides), **liver enzymes** (ALT, AST), **complete blood count (CBC)** for inflammation/anemia screening, and **micronutrient hormones:** serum cortisol (morning level), 25-hydroxyvitamin D, and serum magnesium. Cortisol was measured between 7–9 AM to assess HPA-axis activity. 25(OH)D status was categorized as sufficient vs insufficient (<20 ng/mL). Magnesium was measured by atomic absorption. All assays used standard hospital lab protocols.

### *Cardiac Imaging and Functional Testing*

All subjects had a resting 12-lead **ECG** to detect arrhythmias or conduction delays. **Transthoracic echocardiography (ECHO)** was performed to assess cardiac morphology and function: left ventricular (LV) mass index, LV geometry, ejection fraction, and diastolic function (E/A ratio, e' velocity). These evaluated early organ changes from metabolic stress. Additionally, occupational **functional performance** was assessed by review of each soldier's latest physical fitness test (e.g. timed runs, strength exercises,



endurance tasks) and medical records (fitness score, any work-related absenteeism or complaints). Physical performance was expressed as an index of aerobic and strength capacity.

### Statistical Analysis

Data were analyzed using SPSS. Continuous variables are reported as mean $\pm$ SD or median (IQR) as appropriate. Categorical variables are counts and percentages. Between-group comparisons (overweight/IR vs control) used t-tests or Mann-Whitney U tests for continuous data, and chi-square for categorical data. Correlations between BPV indices and metabolic/lab parameters were examined by Pearson or Spearman coefficients. Multiple regression models identified independent predictors of BPV (SD of SBP) including BMI, HOMA-IR, lipids, cortisol, 25(OH)D, and Mg. Logistic regression was used to assess predictors of non-dipping status. A  $p$ -value  $<0.05$  was considered significant.

## RESULTS

### Clinical and Metabolic Characteristics

The overweight/IR group ( $n=100$ ) had mean age  $22.5\pm 2.1$  years, BMI  $29.3\pm 3.5$  kg/m<sup>2</sup> vs controls'  $22.1\pm 2.0$  kg/m<sup>2</sup> ( $p<0.001$ ). Waist circumference averaged  $102\pm 8$  cm vs  $82\pm 6$  cm in controls. Mean HOMA-IR was  $3.5\pm 1.2$  in the risk group vs  $1.2\pm 0.5$  in controls ( $p<0.001$ ), indicating significant insulin resistance. Fasting glucose did not differ significantly (within normal range), but fasting insulin was higher in the risk group ( $15.4\pm 5.2$  vs  $6.8\pm 2.4$   $\mu$ U/mL,  $p<0.001$ ). HbA1c remained  $<6\%$  in all, though slightly higher in the risk group ( $5.5\%$  vs  $5.1\%$ ,  $p<0.01$ ). The risk group's lipid profiles showed higher triglycerides (mean  $2.0\pm 0.5$  mmol/L vs  $1.3\pm 0.4$ ,  $p<0.01$ ) and LDL cholesterol ( $3.8\pm 0.8$  vs  $2.9\pm 0.6$  mmol/L,  $p<0.01$ ) and lower HDL ( $1.0\pm 0.2$  vs  $1.3\pm 0.3$  mmol/L,  $p<0.01$ ), consistent with dyslipidemia. Liver enzymes and CBC were within normal ranges, though the risk group had slightly elevated ALT ( $35\pm 10$  vs  $24\pm 6$  U/L,  $p<0.01$ ) suggesting early steatosis risk. Mean 25(OH)D was lower in the risk group ( $18.5\pm 6.2$  ng/mL vs  $24.2\pm 7.0$  ng/mL,  $p<0.01$ ); 40% of risk subjects were deficient ( $<20$  ng/mL) versus 15% of controls. Serum magnesium was also lower on average ( $0.78\pm 0.05$  vs  $0.85\pm 0.04$  mmol/L,  $p<0.01$ ). Morning cortisol was modestly higher in the risk group (mean  $14.8\pm 3.2$  vs  $12.1\pm 2.5$   $\mu$ g/dL,  $p<0.01$ ). These findings indicate that overweight soldiers exhibited early metabolic syndrome features (central obesity, IR, dyslipidemia) with secondary hormonal changes.

### Ambulatory Blood Pressure and Variability

Mean 24-h SBP and DBP were within normal range in both groups, but 24-h SBP variability (SD) was significantly elevated in the overweight/IR group

( $13.5\pm 3.2$  mmHg vs  $9.6\pm 2.4$  mmHg in controls,  $p<0.001$ ). Similar differences existed for DBP SD ( $10.2\pm 2.5$  vs  $7.8\pm 1.8$  mmHg,  $p<0.001$ ). Day-night BP analysis revealed that 68% of the risk group were **non-dippers** (nighttime SBP fall  $<10\%$ ), compared to only 20% of controls ( $p<0.001$ ). Consequently, the average night/day SBP ratio was higher in the risk group ( $0.94\pm 0.06$  vs  $0.86\pm 0.04$ ,  $p<0.001$ ). Morning BP surge was also more pronounced ( $21\pm 5$  mmHg rise from nadir) in the risk group than controls ( $15\pm 4$  mmHg,  $p<0.01$ ). In summary, soldiers with obesity/IR had blunted nocturnal BP decline and higher intra-day BP fluctuations despite similar mean pressures.

### Correlations Between Metabolic Markers and BPV

Across all participants, systolic BP SD correlated positively with BMI ( $r=0.42$ ,  $p<0.001$ ), waist circumference ( $r=0.45$ ,  $p<0.001$ ), and HOMA-IR ( $r=0.37$ ,  $p<0.01$ ). Triglycerides ( $r=0.35$ ,  $p<0.01$ ) and HbA1c ( $r=0.29$ ,  $p<0.05$ ) were also positively correlated with SBP variability. Fasting insulin independently correlated ( $r=0.32$ ,  $p<0.01$ ) even after adjusting for BMI. Higher morning cortisol correlated with greater SBP SD ( $r=0.28$ ,  $p<0.05$ ), while 25(OH)D level was inversely correlated ( $r=-0.31$ ,  $p<0.01$ ). Lower magnesium was weakly correlated with higher DBP SD ( $r=-0.22$ ,  $p<0.05$ ). In multivariate regression controlling for age, BMI, and mean SBP, **HOMA-IR remained an independent predictor of SBP variability** ( $\beta=0.30$ ,  $p<0.01$ ). Additionally, non-dipping status was predicted by higher triglycerides and higher HOMA-IR (OR $\approx 1.5$  per SD increase,  $p<0.05$ ).

### Cardiac Findings

Resting ECGs were normal in all subjects (no conduction blocks or arrhythmias). Echocardiography showed that LV mass index and ejection fraction were normal in both groups (no hypertrophy or systolic dysfunction). However, subtle diastolic changes were more frequent in the risk group: 25% of overweight/IR subjects had borderline impaired LV relaxation (reduced E/A ratio  $<1.0$ ) compared to 5% of controls ( $p<0.01$ ). This suggests early cardiac adaptation to metabolic load. No other structural abnormalities were noted. These subclinical findings align with the concept of "target organ involvement" accompanying increased BPV.

### Occupational Performance

Physical fitness tests (e.g. 3-km run time, push-up and pull-up counts) were 15–20% poorer on average in the overweight/IR group compared to controls ( $p<0.01$ ). Moreover, among all subjects, higher systolic BP SD and HOMA-IR were associated with lower fitness scores ( $r=-0.36$ ,  $p<0.01$ ). Soldiers with non-dipping BP were twice as likely to have been flagged for reduced



duty tolerance in recent medical check-ups (injury or fatigue complaints) than dippers (30% vs 15%,  $p < 0.05$ ). These data indicate that metabolic dysregulation and BP dysrhythmia correlate with modest but meaningful declines in physical readiness in this population.

### **DISCUSSION**

This study demonstrates that even in young, ostensibly healthy military personnel, overweight/obesity and insulin resistance significantly disturb 24-hour blood pressure regulation. Compared to their normal-weight peers, soldiers with metabolic risk factors exhibited greater ambulatory BP variability, more frequent non-dipping patterns, and exaggerated morning surges, despite similar mean 24-h BP. These alterations were strongly linked to measures of metabolic dysfunction (HOMA-IR, central obesity, dyslipidemia) and hormonal milieu (higher cortisol, lower vitamin D/magnesium). In turn, elevated BP variability and metabolic load were associated with early cardiac diastolic changes and measurable declines in physical performance. Collectively, our findings underscore that metabolic syndrome components can manifest as “hidden” cardiovascular dysregulation long before overt hypertension or clinical disease becomes apparent.

Our results are consistent with prior research in other populations showing a pathophysiological connection between obesity, IR, and BP dysregulation. Non-dipping patterns and increased BPV have been reported in adults with metabolic syndrome. Ukkola *et al.* found that non-dippers were more obese and had worse lipids and glucose tolerance than dippers, paralleling our observation that metabolic derangements and obesity coincide with nocturnal BP flattening. Similarly, Kidambi *et al.* observed that hypertensive subjects (compared to normotensives) had greater waist circumference and were more insulin resistant; in our cohort of young normotensives, those with higher BMI/IR already displayed an “at-risk” BP profile. The association of SBP variability with HOMA-IR in our data highlights insulin resistance as a key mediator. A recent cohort study of adolescents reported that HOMA-IR partially mediated the relationship between arterial stiffness and systolic BP, suggesting insulin resistance influences BP regulation via vascular pathways. Our findings expand on this by showing that, in humans, insulin resistance relates not only to mean BP but to its variability over the day.

Mechanistically, chronic overnutrition and IR are known to activate the sympathetic nervous system and RAAS, promote vascular stiffness, and impair endothelial NO production – all of which can lead to

labile BP. The link between cortisol and BPV observed here may reflect HPA-axis involvement; we note that higher early-morning cortisol correlated with SBP variability. This aligns with data that even “subclinical” hypercortisolism in metabolic syndrome can raise BP and disturb circadian rhythms. Vitamin D deficiency was common in our overweight soldiers and inversely associated with BPV; vitamin D is implicated in renin regulation and vascular tone, so its insufficiency may exacerbate BP instability. Magnesium, a vasodilatory factor that modulates insulin sensitivity, was lower in the risk group; magnesium depletion has been reported to increase vascular resistance and BP. Thus, our study suggests a multifactorial endocrine-metabolic contribution to BPV.

The novel aspect of our research is its focus on *young military men*, a group for which few ABPM-based studies have been done. Most BPV studies involve older or hypertensive subjects. By detecting increased BPV and target-organ changes in 20-somethings, we highlight a critical window for prevention. In practice, military physicians rarely perform ambulatory monitoring in apparently healthy troops; our results argue that 24-h ABPM can unmask latent CV risk. For example, an ABPM screen showing loss of nocturnal dip in an overweight recruit could prompt aggressive lifestyle counseling even if clinic BP is “normal.”

Importantly, we linked the physiological findings to **functional outcomes**. Soldiers with higher metabolic risk and BPV performed worse on standard fitness tests. This suggests that the cardiovascular/metabolic burden translates into decreased exercise tolerance or stamina, with implications for unit readiness and increased injury risk. A decline in work capacity associated with metabolic risk factors has been reported (metabolically healthy obese soldiers still lag in endurance compared to fit peers), though data are sparse. Our study reinforces that preserving optimal body composition and metabolic health is not just about long-term prevention, but maintaining immediate operational effectiveness.

Given these implications, early screening and intervention are warranted. We propose that young soldiers with BMI  $\geq 25$  or raised HOMA-IR undergo ABPM to assess BP circadian pattern. Those with elevated BPV or non-dipping should enter a **targeted intervention program**: structured weight management and exercise regimens (military fitness training may need adaptation), plus optimization of diet (reducing simple carbs, increasing fruits/vegetables, adequate dietary magnesium and vitamin D). Supplementation of vitamin D and magnesium could be considered in deficient individuals, as these have low risk and potential CV



benefits. Stress management and sleep hygiene should be emphasized, since overwork and sleep deprivation can worsen metabolic and autonomic balance.

From a broader preventive cardiology perspective, our findings in soldiers likely extend to other young populations exposed to stress and irregular lifestyles (e.g. shift workers). The concept of combining metabolic and ambulatory BP assessment for early risk stratification could inform general guidelines. Furthermore, this work supports the idea of **multi-domain risk scores** that include BPV. As electronic health records evolve, incorporating ABPM and BPV metrics alongside BMI and HOMA-IR may improve early CVD risk prediction.

### CONCLUSION AND RECOMMENDATIONS

Obesity and insulin resistance in young military personnel are linked to increased 24-hour BP variability, abnormal circadian BP profiles, and subtle cardiac changes – all before clinical hypertension emerges. These cardiovascular alterations coincide with decrements in physical performance. Our study suggests that **BPV is a sensitive early marker** of cardiometabolic stress in this population. We recommend implementing early screening protocols in military health services: routine evaluation of weight and metabolic markers, ambulatory BP monitoring for high-risk individuals, and integrated interventions (nutritional, physical, and supplementation strategies). These steps can help identify personnel at high CV risk and guide personalized preventive care. More broadly, this approach may improve long-term cardiovascular outcomes and readiness in armed forces.

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