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Original Research Article

FREQUENCY-DOMAIN HEART RATE VARIABILITY AND CARDIOVASCULAR CHARACTERISTICS IN PREMENOPAUSAL AND POSTMENOPAUSAL WOMEN: A CROSS-SECTIONAL STUDY

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ABSTRACT

Background: Menopause is associated with alterations in cardiovascular physiology and autonomic regulation. Heart rate variability (HRV) provides a non-invasive method for evaluating cardiac autonomic modulation. However, the relationship between menopausal status, frequency-domain HRV parameters, blood pressure, and body composition requires further investigation. **Objective:** To compare frequency-domain HRV parameters between premenopausal and postmenopausal women and examine the differences in blood pressure, body weight, and body mass index (BMI) between the groups.

Materials and Methods: This observational cross-sectional study included 110 women, comprising 55 premenopausal and 55 postmenopausal participants. Baseline anthropometric and cardiovascular parameters were recorded. HRV was assessed using a Polar Verity Sense device, with recordings analysed using Kubios HRV software. Frequency-domain parameters included total power, low-frequency (LF) power, high-frequency (HF) power, normalized LF and HF power, and the LF/HF ratio. Continuous variables were expressed as mean ± standard deviation. Between-group comparisons were performed using the unpaired Student's t-test.

Results: Postmenopausal women demonstrated significantly lower total power (1850 ± 650 vs. 2850 ± 850 ms²; p<0.001), absolute LF power (1190 ± 450 vs. 1550 ± 520 ms²; p<0.001), and absolute HF power (630 ± 290 vs. 1280 ± 410 ms²; p<0.001). Normalized LF power was significantly higher in postmenopausal women (65.3 ± 9.1 vs. 54.8 ± 8.5 n.u.; p<0.001), whereas normalized HF power was lower (34.7 ± 9.5 vs. 45.2 ± 8.9 n.u.; p<0.001). The LF/HF ratio was significantly elevated in the postmenopausal group (1.95 ± 0.52 vs. 1.25 ± 0.35; p<0.001). Postmenopausal women also exhibited higher systolic blood pressure (126.3 ± 9.5 vs. 118.4 ± 7.2 mmHg; p<0.001) and diastolic blood pressure (80.9 ± 6.4 vs. 76.5 ± 5.8 mmHg; p=0.006). Body weight was comparable between groups (62.5 ± 9.1 vs. 60.1 ± 8.5 kg; p=0.289).

Conclusion: Postmenopausal women demonstrated lower overall HRV and reduced relative vagal modulation, accompanied by higher blood pressure. The findings suggest an association between menopausal status and altered cardiac autonomic regulation. However, the substantial age difference between the study groups limits the ability to distinguish menopause-associated changes from age-related autonomic decline.

Keywords: Heart rate variability; menopause; autonomic nervous system; frequency-domain analysis; blood pressure; body weight; LF/HF ratio; cardiovascular physiology.

INTRODUCTION

Cardiovascular disease remains a major cause of morbidity and mortality among women worldwide. The menopausal transition represents an important physiological milestone characterized by the cessation of ovarian function and a progressive decline in circulating ovarian hormones, particularly estrogen. This transition is accompanied by changes in vascular function, metabolic regulation, and cardiovascular autonomic control. [1,5]

Heart rate variability (HRV), defined as the variation in consecutive normal-to-normal cardiac intervals, is a widely used non-invasive marker of cardiac autonomic modulation. HRV reflects the dynamic interaction between sympathetic and parasympathetic influences on the sinoatrial node and provides information regarding cardiovascular adaptability. [2,3]

Frequency-domain analysis of HRV separates the variability signal into different spectral components. High-frequency (HF) power is predominantly associated with respiratory-linked vagal modulation, whereas low-frequency (LF) power reflects a combination of sympathetic and parasympathetic influences and baroreflex-related oscillations. The LF/HF ratio has traditionally been used as an index of sympathovagal balance; however, its physiological interpretation remains debated.[3]

Oestrogen has been implicated in the regulation of cardiovascular autonomic function through its effects on central autonomic pathways, vascular endothelial function, nitric oxide production, and baroreflex sensitivity. Declining oestrogen concentrations after menopause may contribute to alterations in autonomic regulation. [4,5,6,7]

Previous studies have reported lower HRV in postmenopausal women, particularly in parasympathetic-associated parameters. However, the relative contributions of chronological aging, menopausal status, body composition, and blood pressure remain incompletely understood. [4,8,9,10]

Blood pressure and body composition are important cardiovascular characteristics that may influence cardiac autonomic modulation. Increased blood pressure may be associated with altered baroreflex function, while excess body weight and adiposity may influence autonomic regulation through metabolic and inflammatory pathways. [3,5]

Despite these associations, simultaneous assessment of frequency-domain HRV parameters, blood pressure, and anthropometric measurements may provide a more comprehensive understanding of cardiovascular autonomic differences between premenopausal and postmenopausal women.

The present study therefore compared frequency-domain HRV parameters between premenopausal and postmenopausal women and evaluated differences in blood pressure, body weight, and BMI.

2. Aim and Objectives

Aim

To evaluate cardiac autonomic modulation using frequency-domain HRV analysis in premenopausal and postmenopausal women.

Objectives

1. To compare absolute and normalized frequency-domain HRV parameters between premenopausal and postmenopausal women.
2. To compare systolic and diastolic blood pressure between the two groups.
3. To compare body weight and BMI between premenopausal and postmenopausal women.
4. To explore the relationship between duration since menopause and selected HRV parameters.

MATERIALS AND METHODS

3.1 Study Design and Setting

The study was an observational, cross-sectional comparative study conducted at a tertiary-care teaching hospital in SMIMER Surat, Gujarat, India.

The study evaluated cardiac autonomic function in women classified according to menopausal status.

3.2 Study Population and Sample Size

A total of 110 women were included in the study.

Participants were divided into two groups:

- Group I: Premenopausal women (n=55).
- Group II: Postmenopausal women (n=55).

3.3 Inclusion Criteria

The following criteria were used for participant selection:

A total of 110 healthy adult female volunteers were recruited from the OPD of Obst and Gayne department and from other departments of the college. A preliminary screening was done to assess age and menstrual history to place them into potential premenopausal and postmenopausal groups.

Premenopausal group:

- Women aged between 18-45 years presenting with regular, uninterrupted menstrual cycles (21–35 days) over the preceding 12 months.

Postmenopausal group:

- Women reporting spontaneous, permanent amenorrhea lasting for a minimum duration of 12 consecutive months without any secondary pathological or surgical cause.

3.4 Exclusion Criteria

Participants with the following conditions were excluded: Individuals with a history of documented essential hypertension, type II diabetes mellitus, underlying ischemic heart disease, cardiac arrhythmias, renal or hepatic insufficiencies, active smokers, or those consuming medications known to disrupt autonomic physiology (e.g., beta-blockers, anti-arrhythmic agents, or hormone replacement therapy) were excluded.

3.5 Baseline Assessment

Demographic, anthropometric, and cardiovascular parameters were recorded using a structured evaluation proforma.

The following variables were assessed:

- Age (years).
- Height (cm).
- Body weight (kg).
- Body mass index (kg/m²).
- Systolic blood pressure (SBP; mmHg).
- Diastolic blood pressure (DBP; mmHg).
- Resting heart rate (beats/min).
- Menstrual and menopausal history.
- Duration since menopause (years).

Blood pressure was measured in the seated position after five minutes of rest.

BMI was calculated using the following formula:

BMI = Weight (kg) / Height² (m²)

3.6 **Experimental Protocol and Data Acquisition**

To minimize circadian fluctuations, all evaluations were scheduled uniformly between 09:00 AM and 11:00 AM. Subjects were instructed to fast for at least 2 hours, secure adequate nocturnal rest, and strictly abstain from caffeine, intense physical exertion, or tobacco for 12 hours preceding the test.

Participants were placed in a quiet, dimly lit, temperature-controlled room maintained at approximately 22–24°C and allowed to habituate in a supine resting state for 10 minutes. They were instructed to breathe normally and avoid speaking, sleeping, or unnecessary movements during the recording. Baseline anthropometric parameters including height (meters), weight (kilograms), and Body Mass Index were documented alongside resting blood pressure measurements. Short-term (5-minute) digital physiological cardiac signals were recorded using standardized instrumentation.

3.7 HRV Recording

A Short term (5 -minute) HRV recording was obtained using the Polar Verity Sense device.

3.8 HRV Analysis

The raw R-R interval data streams were algorithmically inspected to isolate clean, normal-to-normal (N-N) configurations. Power spectral analysis was performed using Fast Fourier Transform (FFT) equations to extract the frequency parameters:

The parameters included

Parameter	Frequency range / unit	Interpretation
Total power	ms²	Overall spectral HRV power
LF power	0.04–0.15 Hz; ms²	Mixed autonomic and baroreflex-related modulation
HF power	0.15–0.40 Hz; ms²	Predominantly respiratory-linked vagal modulation
LF normalized units	n.u.	Relative LF contribution
HF normalized units	n.u.	Relative HF contribution
LF/HF ratio	Dimensionless	Traditional index of relative LF-to-HF power

Normalized LF and HF values were interpreted as relative spectral components rather than direct measurements of sympathetic and parasympathetic nerve activity.

3.8 Statistical Analysis

Continuous variables were expressed as mean ± standard deviation.

Group means were compared utilizing the independent Student's t-test. Statistical significance limits were fixed at a two-tailed *p*-value of less than 0.05 ($p < 0.05$).

3.9 Ethical Considerations

Study Setting and Ethical Framework

This cross-sectional study was done by the Department of Physiology at the Surat Municipal Institute of Medical Education and Research (SMIMER), Surat, Gujarat, India. Official protocols were approved by the Institutional Ethics Committee (Ref No: 142-24/02/2025; Approval Notification: SMIMER/IEC/OUT/NO. 103). All participants volunteered written informed consent after a complete briefing regarding the non-invasive nature of the tests.

RESULTS

4.1 Baseline Characteristics

The study included 110 women, with 55 participants in each group.

The postmenopausal group was significantly older than the premenopausal group.

Body weight and BMI were comparable between groups, whereas systolic and diastolic blood pressure were significantly higher in postmenopausal women.

Table 1: Baseline demographic, anthropometric, and cardiovascular characteristics

Parameter	Premenopausal (n=55)	Postmenopausal (n=55)	p-value
Age (years)	35.2 ± 4.1	54.8 ± 5.3	<0.001
Height (cm)	158.5 ± 6.2	156.8 ± 5.9	0.265
Weight (kg)	60.1 ± 8.5	62.5 ± 9.1	0.289
BMI (kg/m²)	23.9 ± 2.8	25.4 ± 3.2	0.051
Systolic BP (mmHg)	118.4 ± 7.2	126.3 ± 9.5	<0.001
Diastolic BP (mmHg)	76.5 ± 5.8	80.9 ± 6.4	0.006
Resting heart rate (bpm)	72.3 ± 6.0	78.5 ± 7.2	<0.001

Data are presented as mean ± SD.

The premenopausal group had a mean age of 35.2 ± 4.1 years, while the postmenopausal group was

significantly older with a mean age of 54.8 ± 5.3 years ($p<0.001$), confirming the expected age difference based on menopausal status

4.2 Frequency-Domain HRV Parameters

Frequency-domain analysis demonstrated significant differences in spectral HRV parameters between the two groups.

Total power was significantly lower in postmenopausal women, indicating reduced overall spectral variability.

Absolute LF and HF power were also significantly reduced. The reduction in absolute HF power was more pronounced than the reduction in LF power.

Normalized LF power was significantly higher in postmenopausal women, whereas normalized HF power was significantly lower.

The LF/HF ratio was significantly elevated in the postmenopausal group.

Table 2: Comparison of frequency-domain HRV parameters

HRV parameter	Premenopausal (n=55)	Postmenopausal (n=55)	p-value
Total power (ms²)	2850 ± 850	1850 ± 650	<0.001
LF power (ms²)	1550 ± 520	1190 ± 450	<0.001
HF power (ms²)	1280 ± 410	630 ± 290	<0.001
LF power (n.u.)	54.8 ± 8.5	65.3 ± 9.1	<0.001
HF power (n.u.)	45.2 ± 8.9	34.7 ± 9.5	<0.001
LF/HF ratio	1.25 ± 0.35	1.95 ± 0.52	<0.001

Data are presented as mean ± SD.

4.3 Comparison of HRV with Blood Pressure

Postmenopausal women exhibited significantly higher systolic and diastolic blood pressure than premenopausal women.

The difference in systolic blood pressure was 7.9 mmHg, while the difference in diastolic blood pressure was 4.4 mmHg.

These findings occurred alongside lower total power and HF power and a higher LF/HF ratio in the postmenopausal group.

Table 3: Between-group differences in blood pressure and frequency-domain HRV

Parameter	Premenopausal	Postmenopausal	Difference
Systolic BP (mmHg)	118.4	126.3	+7.9
Diastolic BP (mmHg)	76.5	80.9	+4.4
Total power (ms²)	2850	1850	−1000
HF power (ms²)	1280	630	−650
HF power (n.u.)	45.2	34.7	−10.5
LF/HF ratio	1.25	1.95	+0.70

The observed differences indicate that higher blood pressure at the group level co-occurred with lower HRV in postmenopausal women.

4.4 Comparison of HRV with Body Weight and BMI

The mean body weight of postmenopausal women was 2.4 kg higher than that of premenopausal women. However, this difference was not statistically significant.

BMI was also higher in postmenopausal women, although the difference did not reach statistical significance.

Table 4: Anthropometric comparison

Parameter	Premenopausal	Postmenopausal	p-value
Weight (kg)	60.1 ± 8.5	62.5 ± 9.1	0.289
BMI (kg/m²)	23.9 ± 2.8	25.4 ± 3.2	0.051

The findings suggest that the observed HRV differences were not accompanied by a statistically significant difference in mean body weight.

However, the possibility of confounding by age, BMI, body fat distribution, or other unmeasured variables cannot be excluded.

4.5 Association Between Duration Since Menopause and HRV

The data reported shows significant correlations between duration since menopause and selected HRV parameters.

Table 5: Correlation of HRV parameters with years since menopause

Parameter	Correlation coefficient (r)	p-value
HF power (n.u.)	−0.48	0.007
LF/HF ratio	+0.55	0.002

Longer duration since menopause was associated with lower overall HRV and lower vagal-associated indices, while the LF/HF ratio increased which indicates sympathetic dominance increases with time since menopause.

These findings suggest a relationship between duration since menopause and cardiac autonomic modulation. However, the cross-sectional design does not establish a temporal or causal relationship.

DISCUSSION

The present study evaluated frequency-domain HRV parameters in premenopausal and postmenopausal women and examined differences in blood pressure, body weight, and BMI.

The principal findings were:

1. Postmenopausal women demonstrated significantly lower total HRV spectral power.
2. Absolute HF power was markedly reduced in postmenopausal women.
3. Normalized LF power and the LF/HF ratio were significantly higher in postmenopausal women.
4. Systolic and diastolic blood pressure were significantly higher in the postmenopausal group.
5. Body weight and BMI did not demonstrate statistically significant between-group differences.
6. Longer duration since menopause was associated with lower vagal-associated HRV parameters.

5.1 Menopausal Status and Frequency-Domain HRV

The present study demonstrated a significant reduction in total power in postmenopausal women.

Total power represents the overall variance captured by the analysed HRV spectrum. Its reduction suggests diminished overall cardiac autonomic modulation. [2,3]

The reduction in absolute HF power was more pronounced than the reduction in absolute LF power. HF power is closely associated with respiratory sinus arrhythmia and cardiac vagal modulation. The observed decrease in HF power may therefore indicate reduced vagal influence on the sinoatrial node.[3]

The decrease in absolute LF power should not, however, be interpreted as direct evidence of reduced sympathetic activity. LF power reflects a combination of autonomic influences, including baroreflex-related oscillations.[3]

The increase in normalized LF power and reduction in normalized HF power indicate a relative redistribution of spectral power.

The LF/HF ratio was higher in postmenopausal women, suggesting an altered relationship between LF and HF oscillations.

Although these findings are compatible with altered autonomic regulation, the LF/HF ratio should not be considered a definitive quantitative measurement of sympathetic dominance. Current HRV interpretation recognizes that LF and HF components are influenced by several physiological factors, including respiration, baroreflex activity, and recording conditions.[3]

5.2 Blood Pressure and Cardiac Autonomic Modulation

Postmenopausal women had significantly higher systolic and diastolic blood pressure than premenopausal women.

The observed increase in blood pressure occurred alongside lower total power, lower HF power, and a higher LF/HF ratio.

Several physiological mechanisms may contribute to this association.

Age-related changes in arterial compliance and baroreceptor sensitivity may influence cardiovascular autonomic regulation. Changes in vascular endothelial function and hormonal status may also contribute to alterations in blood pressure regulation. [3,5]

The baroreflex plays an important role in maintaining short-term blood pressure stability by modifying cardiac autonomic output in response to changes in arterial pressure.[3]

Altered baroreflex function may therefore influence both blood pressure and HRV.

However, the present study cannot determine whether the higher blood pressure contributed to the lower HRV, whether autonomic alterations influenced blood pressure, or whether both were influenced by age and other factors.

Furthermore, the study excluded women with diagnosed hypertension. The observed differences should therefore be interpreted as differences in resting blood pressure within the selected study population rather than evidence of established hypertension.

5.3 Body Weight, BMI, and HRV

Body weight was comparable between the two groups.

Although postmenopausal women had a higher mean BMI, the difference did not reach statistical significance.

The reduction in HRV in the postmenopausal group was therefore observed without a statistically significant difference in mean body weight.

Nevertheless, body weight alone does not adequately represent adiposity or metabolic status.

BMI does not distinguish between fat mass and lean mass and does not assess central adiposity. Differences in waist circumference, visceral fat, insulin sensitivity, and physical activity may influence autonomic regulation independently of total body weight.

The present study did not provide individual-level correlations between HRV and body weight or BMI. Consequently, it is not possible to determine whether women with higher body weight had lower HF power or higher LF/HF ratios within either study group.

Future studies should evaluate the relationship between HRV and anthropometric variables using individual participant data and multivariable statistical models.

5.4 Duration Since Menopause and Autonomic Modulation

The present study demonstrated negative correlations between duration since menopause and normalized HF power.

The LF/HF ratio showed a positive correlation with duration since menopause.

These findings suggest that longer duration since menopause was associated with lower HRV and a relative reduction in vagal-associated spectral modulation.

However, because the study was cross-sectional, it cannot establish whether HRV progressively declines within individuals after menopause.

Longitudinal studies following women through the menopausal transition would provide stronger evidence regarding the temporal relationship between menopause and cardiac autonomic changes.

5.5 Comparison with Previous Research

The findings are broadly consistent with previous investigations reporting lower HRV in postmenopausal women.

Subhashri et al. reported reduced normalized HF power and increased normalized LF power and LF/HF ratio in postmenopausal women. They also reported higher blood pressure in the postmenopausal group. [8,10]

Singh et al. reported a trend toward lower frequency-domain HRV parameters in postmenopausal women, although some between-group differences were not statistically significant.[9]

Ramesh et al. investigated HRV in relation to menopausal status, estradiol concentrations, and physiological stress. Their findings highlighted the importance of age and body composition in interpreting menopausal differences in HRV.[4]

The present findings add to this literature by presenting a comparative analysis of absolute and normalized spectral HRV parameters alongside blood pressure and anthropometric characteristics.

Nevertheless, the substantial age difference between the present study groups is an important limitation when comparing these findings with age-matched studies.

5.6 Clinical Implications

HRV provides a non-invasive method for evaluating cardiac autonomic modulation. [2,3]

The observed differences in HRV and blood pressure suggest that postmenopausal women may exhibit a different cardiovascular autonomic profile compared with premenopausal women.

However, HRV is not a standalone diagnostic test for cardiovascular disease. [1,5]

The present study did not evaluate cardiovascular events, clinical outcomes, or the predictive accuracy of HRV for future cardiovascular disease.

Therefore, the findings should be considered physiological observations rather than evidence that the HRV parameters can independently predict cardiovascular risk.

Further research is required to determine whether HRV assessment can provide clinically meaningful information beyond conventional cardiovascular risk factors.

6. Strengths and Limitations

Strengths

- Equal numbers of premenopausal and postmenopausal participants were included.
- HRV was assessed using a standardized five-minute resting recording.
- Both absolute and normalized frequency-domain parameters were evaluated.
- Blood pressure and anthropometric characteristics were assessed alongside HRV.
- Duration since menopause was considered in the analysis.

Limitations

Several limitations should be acknowledged.

First, the cross-sectional design does not establish causality or determine the temporal sequence of autonomic changes.

Second, the postmenopausal group was substantially older than the premenopausal group. The effects of chronological aging and menopausal status therefore cannot be separated using the reported unadjusted comparisons.

Third, although body weight and BMI were compared between groups, individual-level correlations between HRV parameters and anthropometric measurements were not available in the reported tables.

Fourth, individual-level correlations between blood pressure and frequency-domain HRV parameters were not reported.

Fifth, the study did not provide multivariable-adjusted estimates accounting for age, BMI, blood pressure, physical activity, or other potential confounders.

Sixth, the physiological interpretation of LF power and the LF/HF ratio remains complex. These parameters should not be regarded as direct measurements of sympathetic nerve activity.

Finally, the study was conducted at a single tertiary-care teaching hospital, which may limit the generalizability of the findings.

CONCLUSION

Postmenopausal women demonstrated significantly lower total HRV spectral power and reduced absolute and normalized HF power compared with premenopausal women.

The postmenopausal group also demonstrated higher normalized LF power and a higher LF/HF ratio, suggesting altered relative cardiac autonomic modulation.

Systolic and diastolic blood pressure were significantly higher in postmenopausal women, whereas body weight and BMI did not demonstrate statistically significant between-group differences.

The findings indicate an association between menopausal status and altered cardiac autonomic regulation.

However, the substantial age difference between the study groups and the absence of individual-level correlation and adjusted analyses limit the ability to attribute the observed differences specifically to menopause.

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