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Does reproductive stage impact cardiovascular disease risk factors? Results from a population-based cohort in Lausanne (CoLaus study)

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Abstract

Context: Menopause has been associated with adverse cardiovascular disease (CVD) risk profile, yet it is unclear whether the changes in CVD risk factors differ by reproductive stage independently of underlying ageing trajectories.

Design: The CoLaus study is a prospective population-based cohort study in Lausanne, Switzerland.

Patients: We used data from women at baseline and follow-up (mean: 5.6 ± 0.5 years) from 2003 to 2012 who did not use hormone therapy. We classified women into (i) premenopausal, (ii) menopausal transition, (iii) early (≤5 years) and (iv) late (>5 years) postmenopausal by comparing their menstruation status at baseline and follow-up.

Measurements: We measured fasting lipids, glucose and cardiovascular inflammatory markers. We used repeated measures (linear mixed models) for longitudinal analysis, using premenopausal women as a reference category. We adjusted analyses for age, medications and lifestyle factors.

Results: We used the data from 1710 women aged 35–75 years. Longitudinal analysis showed that the changes in CVD risk factors were not different in the other three menopausal categories compared to premenopausal women. When age was used as a predictor variable and adjusted for menopause status, most CVD risk factors increased, while interleukin-6 and interleukin-1β decreased with advancing age.

Conclusion: The current study suggests that women have a worsening cardiovascular risk profile as they age, and although menopausal women may have higher levels of cardiovascular risk factors compared to premenopausal women at any given time, the 5-year changes in cardiovascular risk factors may not depend on the reproductive stage.

KEYWORDS

cardiovascular diseases, cardiovascular system, female, menopause, reproduction, risk factors

Peter F. Raguindin and Isabel Cardona contributed equally to this study.

1 | INTRODUCTION

Natural menopause is defined as the absence of menstrual periods for 12 consecutive months for which there is no other obvious pathological or physiologic cause.[1] It is a consequence of the depleted pool of primary ovarian follicles and the termination of folliculogenesis, resulting in a decline in oestrogen production and an increase in iron body stores due to the cessation of menses.[1] Although women reach menopause at the average age of 50–52 years, the menopausal transition may start several years before the last menstrual period.[2,3] The menopause transition phase is a period characterized by fluctuations in sex hormones and the presence of menopausal symptoms that could be highly troublesome, requiring hormone therapy.[4,5]

Changes in the sex hormone levels occurring around the menopause onset have been associated with metabolic changes, resulting in slower lipid metabolism, impairment of glucose tolerance and increased body weight,[6] leading to higher cardiovascular morbidity and mortality in ageing women.[7–10] Further, menopausal symptoms have been associated with increased cardiovascular risk factors, increased risk of coronary heart disease, and increased all-cause and cardiovascular disease (CVD) mortality.[8,10,11] Thus, menopause has been suggested as a risk factor for developing cardiometabolic diseases (CVD, metabolic syndrome and type 2 diabetes).[12–14] Indeed, the incidence of CVD is increased in the postmenopausal period, thus, consensus statements from leading experts have made this a priority for cardiovascular prevention in women's health.[15,16] Cross-sectional studies have consistently reported more adverse cardiovascular risk profiles for postmenopausal women than premenopausal women.[17–24] Although the findings from longitudinal studies have been conflicting, some studies suggested increased cardiometabolic risk factors for advanced reproductive stages.[25–29] Therefore, it remains insufficiently explored whether increased cardiometabolic risk after menopause is a direct consequence of transitioning through menopause or it is a result of cumulative ageing. In this context, we performed a cross-sectional and longitudinal analysis using data from a prospective cohort of Swiss women to explore the changes in CVD risk factors according to the reproductive stage and considering the role of chronological age.

2 | MATERIALS AND METHODS

2.1 | Study population

The CoLaus study is a single-centre, population-based cohort study in Lausanne, Switzerland established in 2003 to investigate the epidemiology of CVD and metabolic syndrome in the area.[30,31] The study enrolled adults between 35 and 75 years of age of Caucasian origin from 2003 to 2006. Caucasian origin was defined as having both parents and grandparents from a list of countries specified by the study group. The total population of adults meeting these criteria was 56,694, of which 19,830 were selected through simple random sampling by electronic draw, comprising 35% of the source population. Among these 15,109 (76.19%) responded to the invitation, for which 799 were ineligible, and 6189 refused to participate. Thus, only 8121 were eligible for baseline interviews. Ultimately, 6104 adults completed the baseline interview. A follow-up visit was then scheduled between 2009 and 2012. The average time between the visits was 5.6 (±0.5) years. For the current analysis/study, we used data on baseline and first follow-up (Figure S1).

2.2 | Classification of exposure (reproductive stage)

The reproductive staging was based on a self-reported prospective evaluation of menstrual bleeding at baseline and follow-up. Women were asked if they had menstrual bleeding during the year preceding the clinic visit. We classified the women into four reproductive stages based on their baseline menstruation status and follow-up. The groups were as follows: premenopause (PRE), transition or perimenopause (TRANS), early postmenopause (EPOST) and late postmenopause (LPOST) (see Figure 1). PRE was identified as having menstrual bleeding at baseline and follow-up. TRANS were those who had menstrual bleeding at baseline but had no bleeding on follow-up (women became postmenopausal during the follow-up period), EPOST those women without menstrual bleeding for 1–5 years at baseline, and LPOST those with amenorrhoea for 5 years or more at baseline. Women with ovarian cancer or any malignancy requiring ovarian surgery, hysterectomy (with or without oophorectomy), or chemotherapy were classified under postmenopause and analysed in this group. Statistical analysis of natural menopause (those without any surgery) and those with concurrent medication use (antihypertensives, statins/antilipidemic and oral hypoglycaemics/antidiabetic drugs) are discussed in another section.

2.3 | Inclusion and exclusion criteria

We included all women from the CoLaus cohort (35–75 years, of Caucasian origin, with consent to participate). We restricted our analyses to all women with known menstruation status to facilitate their reproductive stage classification. Furthermore, we removed dropouts for our cross-sectional and longitudinal analysis (women with no information at follow-up).

Of 6104 CoLaus participants, we included 3544 women (see Figure 1). We removed 891 who had no available follow-up data. We also removed 95 women who did not have information on menstruation status or with inconsistent menstruation information. In detail, we used the age of last menstruation to detect inconsistent menstruation information. At baseline, 39 of 1906 women who reported no menstrual bleeding had no age of last menstrual period (2.04% erroneous response), and 41 of 1908 women who had an age of last menstrual period claimed menstrual bleeding (2.14%

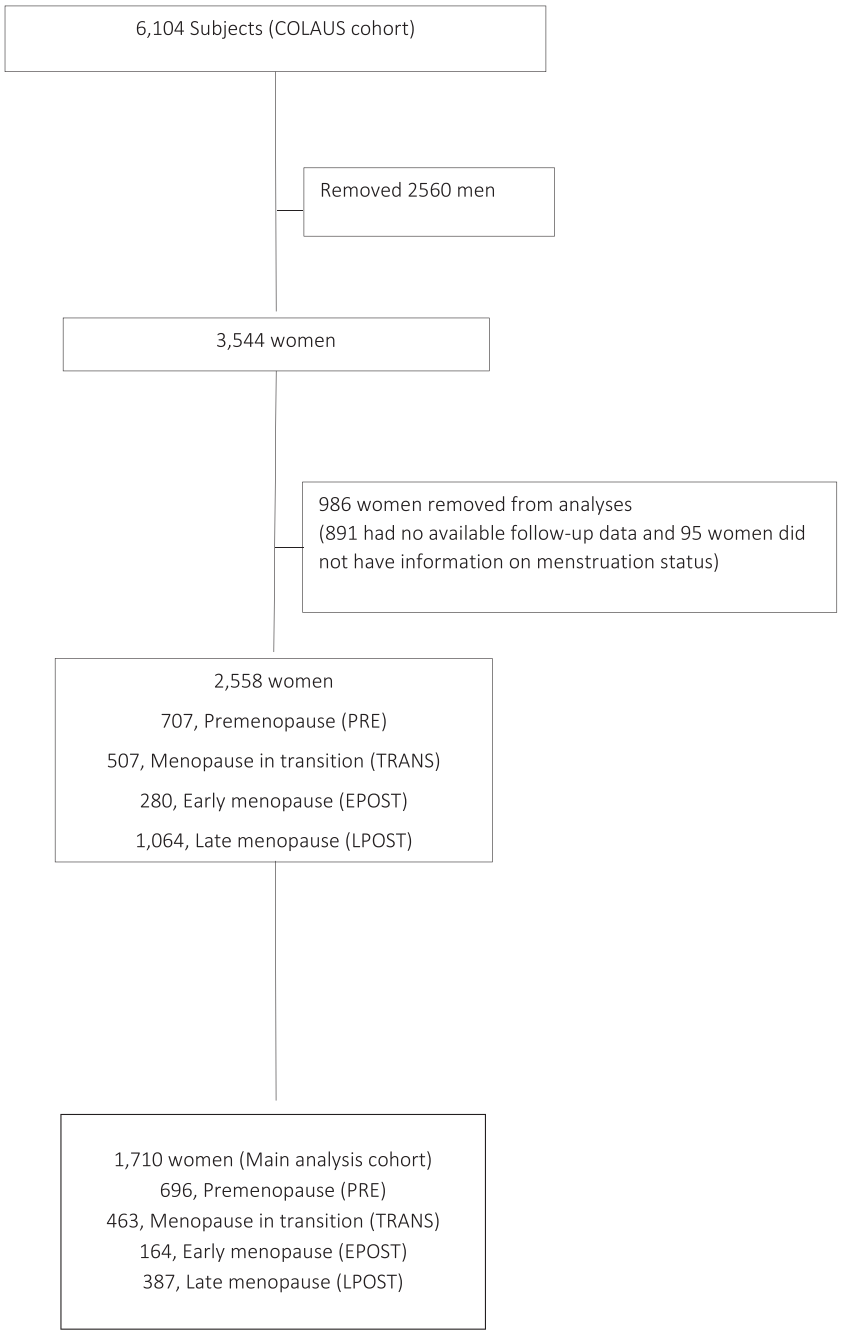

FIGURE 1 Flowchart of study participants

erroneous response). At follow-up, 59 of 1935 women with no menstrual bleeding reported no age of last menstrual period (3.04% erroneous response), and 59 of 1885 women with a reported age of last menstrual period claimed menstrual bleeding (3.12% erroneous response). Furthermore, we found eight women who replied not having menstrual bleeding (menopause) at baseline but reported menstrual bleeding (premenopausal) on follow-up (8/2653 women with follow-up data or 0.3% erroneous response). A total of 2558 women were eligible for analysis. For the final analysis cohort, we excluded 848 women with current and ever-use of hormone therapy. Thus, we used data on 1710 women for cross-sectional and longitudinal analysis (Figure 1).

From this database, we extracted the age, incident and prevalent cardiometabolic diseases, smoking, drinking habits, physical activity, medication use and menstrual bleeding status of women at baseline (2003–2006) and first follow-up visit (2009–2012).

2.4 | Measurement of outcome (cardiovascular risk factors)

Weight and height were measured using the same scale that underwent serial calibration during the study period. Body mass index (BMI) was calculated from the standard formula (weight in

kilograms divided by height in metres squared). Systolic and diastolic blood pressure (BP) were assessed in a seated position after a 10 min rest using Omron® HEM-907 automated oscillometric sphygmomanometer. We recorded the average of the last two measurements (out of three attempts) expressed in mmHg. We computed the 10-year cardiovascular risk of women using the Framingham risk score (FRS) using a formula from a previous publication.[32] We also computed for insulin resistance index using Homeostatic Model Assessment for Insulin Resistance based on a previous publication.[33]

Venous blood samples (50 ml) were obtained from each participant after overnight fasting. Serum lipids and glucose assays were performed by the Centre Hospitalier Universitaire Vaudois (CHUV) Clinical Laboratory. Inflammatory markers were also measured, namely, high-sensitivity C-reactive protein (hsCRP), interleukin-6 (IL-6), interleukin-1β (IL-1β), adiponectin, leptin and tumour necrosis factor-alpha (TNF-α). Laboratory analyses were performed within the time frame of blood sample collection.

Baseline TNF-α, IL-6 and IL-1β were measured using multiplex particle-based flow cytometric cytokine assay (Luminex®) with the lowest detection limit of 0.2 pg/ml. Intra- and interassay coefficients of variation were 12.5% and 13.5% for TNF-α, 16.9% and 16.1% for IL-6, and 15% and 16.7% for IL-1β. Leptin and adiponectin at baseline were measured using enzyme-linked immunoassay (ELISA) (R&D Systems Inc.) with a maximum interassay coefficient of variation (CV) of 12.8% and 8.3%, respectively. On follow-up, we used multiplexed particle-based flow cytometric cytokine assay (Luminex®) with CV 9.5%. hsCRP was measured using latex immunoassay (Roche Diagnostics, interbatch coefficient of variability, CV, 4.6%–1.3% on baseline and 8.0%–7.4% on follow-up). Leptin and adiponectin were measured using ELISA (American Laboratory Products Co., CV: 12.8%–5.8% and R&D Systems Inc., CV: 8.3%–8.3%). Details of other routine laboratory assays can be found in the online Supporting Information.

2.5 | Measurement of covariates

Information on age, educational attainment, alcohol consumption, tobacco use and physical activity were obtained through a self-administered questionnaire. Educational attainment was defined as 'high' for those with at least a university degree, 'middle' for those who finished secondary school or apprenticeship and 'low' for those who completed mandatory elementary education. Alcohol use was obtained by asking if participants regularly consume alcohol and asking for their weekly consumption before the assessment (wine, beer and spirits; units per week). Tobacco use was self-reported, and participants were classified as current, former smoker or never smokers. Physical activity was elicited by asking the frequency of exercise for at least 20 min in a day per week in each participant. Prevalent CVD, diabetes and medication use (antihypertensive drugs, antidiabetic drugs or statins) were collected using a recruiter administered questionnaire. Hormone therapy use was also obtained through a questionnaire (current or ever used).

2.6 | Statistical analysis

We used linear regression analysis to determine the association between reproductive stages (independent variable) and cardiovascular risk factors (dependent variable). Iterative models were developed to correct for (a) outcome-specific medication use (antilipid drugs/statins for cholesterol, triglycerides, high-density lipoprotein (HDL) and low-density lipoprotein (LDL); antidiabetics/hypoglycemic drugs for insulin, fasting glucose and insulin resistance index; and antihypertensive drugs for systolic and diastolic BP), (b) chronologic age, (c) baseline health and social factors (baseline CVD, educational attainment, alcohol consumption, tobacco use and physical activity), (d) BMI that was added incrementally. We used PRE as the reference group in the linear regression model. Covariates selected for adjustments were based on current literature and scientific plausibility for the association of menopause and CVD (see online Supporting Information).

To explore the longitudinal changes, we examined the changes (mean difference) of cardiovascular risk factors between baseline and follow-up within each reproductive stage using paired *t*-test. We used a multilevel mixed-model approach fitted using a random-slope model to examine the association of cardiovascular risk factors (dependent variable) of different reproductive stages (independent variable). The PRE was used as a reference category. Since the reproductive stage could be correlated with the time gap of observation, we included an interaction term of these two factors (reproductive stage and time gap) in our regression model.

To determine the influence of chronologic age, we iterated the cross-sectional and longitudinal analysis using age as the independent variable. We performed regression using the adjustments as previously mentioned, with the addition of menstruation status. We compared the fully adjusted models using reproductive stage and chronologic age as independent variables to determine which was more associated with longitudinal changes in cardiovascular risk factors.

In sensitivity analyses, we compared the women included in the cohort and those excluded from the analysis to investigate any selection bias in cross-sectional and longitudinal analyses. In addition, we restricted the analyses to specific women groups, namely: (i) women who reported natural menopause (removed women with ovarian surgery, hysterectomy with or without oophorectomy and chemotherapy menopause), and (ii) women without comorbidities (no intake of medications namely, antilipids/statins, antidiabetics/oral hypoglycemics and antihypertensive drugs, no prevalent CVD and no prevalent diabetes). We iterated for both cross-sectional and longitudinal analyses for both of these groups. We explored the use of time-varying covariates considering changes in smoking and alcohol consumption habits across time. Finally, to gain higher statistical power, we performed iteration of all mentioned models to include women with hormone therapy use (data on 2558 women).

All analyses were performed using STATA 15.1 for Windows (STATA Corp.). All computations were done using two-tailed tests.

p Value less than .05 was considered significant, yet we used Bonferroni correction to adjust for multiple testing. We analysed the women with available outcomes (baseline and follow-up). We did list-wise deletion for those with incomplete outcomes.

2.7 | Ethical consideration

The institutional Ethics Committee of the University of Lausanne, which afterwards became the Ethics Commission of Canton Vaud (www.cer-vd.ch), approved the baseline CoLaus study (reference 16/03). The approval was renewed for the first (reference 33/09) follow-up. The study is compliant with the Swiss Human Research Act (810.30 Federal Act of 30 September 2011 on Research involving Human Beings) and Federal Regulations on Data Protection (235.1 Federal Act of 19 June 1992 on Data Protection). The database was managed and kept at the Institute of Social and Preventive Medicine—University of Bern. Written informed consent was obtained from the participants upon their visit for clinical assessment. To maintain the anonymity of the participants, we removed all identifying information not relevant to the analysis.

3 | RESULTS

3.1 | Baseline characteristics

We used data from 1710 women for both cross-sectional and longitudinal analysis. Based on menstruation status at baseline and follow-up, women were classified as premenopausal (PRE, $n = 696$), women in menopause transition (TRANS, $n = 463$), women in early (EPOST, $n = 164$) and late menopause (LPOST, $n = 387$), Figure 1. The baseline characteristics are summarized in Table 1. The clinical characteristics of excluded participants, clinical profile of included participants on follow-up, and missing data table can be found in Table S1A–C. The details of women with paired data used for the analysis (outcome data on baseline and follow-up) can be found in Table S1B.

At baseline, most of the advanced reproductive stages have higher cardiovascular risk factors, with some exceptions. Insulin, leptin, TNF-α, and IL-1β were higher in PRE (insulin: 7.27 ± 4.54 micro IU/ml; leptin: 1.25 ± 0.90 ng/ml; TNF-α: 11.4 ± 131.6 pg/ml; and IL-1β 5.64 ± 52.4 pg/ml) compared to TRANS (insulin: 7.08 ± 4.27 micro IU/ml; leptin 1.28 ± 0.96 ng/ml; and IL-1β 4.15 ± 15.5) (Table 1). The mean BMI was highest (26.8 ± 5.4 kg/m^2), and hypertension (47.6%), diabetes (9.8%), CVD (9.3%) and the use of antihypertensive (25.6%) and antidiabetic (6.5%) medications were the most prevalent in LPOST group (Table 1). In women without a history of CVD, FRS were also substantially higher in EPOST and LPOST (6.37 ± 4.08 and 10.92 ± 7.2) compared to PRE and TRANS (2.32 ± 1.76 and 3.94 ± 2.57).

3.2 | Reproductive stage versus chronologic age: Association with cardiovascular risk factors (cross-sectional analysis)

Using reproductive stage as independent variable (fully-adjusted model) (Tables 2 and S2a), the EPOST and LPOST groups had higher BMI ($\beta = 1.5$, 95% confidence interval [CI]: 0.5, 2.4; and $\beta = 2.4$, 95% CI: 1.3, 3.4), total cholesterol ($\beta = .4$, 95% CI: 0.2, 0.6; and $\beta = .2$, 95% CI: 0.02, 0.5), adiponectin ($\beta = .2$, 95% CI: 0.1, 0.4; and $\beta = .2$, 95% CI: 0.1, 0.4) and IL-6 ($\beta = .4$, 95% CI: 0.1, 0.7; and $\beta = .5$, 95% CI: 0.1, 0.9) compared to PRE group (Table 2). Serum triglyceride ($\beta = .1$, 95% CI: 0.02, 0.2), fasting glucose ($\beta = .2$, 95% CI: 0.03, 0.4), hsCRP ($\beta = .2$, 95% CIL: 0.03, 0.3), and leptin ($\beta = .2$, 95% CI: 0.03, 0.3) was higher in LPOST compared to the reference group (PRE). The incremental addition of covariates showed that the coefficients (EPOST and LPOST) were positive for BMI, diastolic BP, total cholesterol, LDL, triglycerides, fasting glucose, insulin, insulin resistance index, leptin, and IL-6 (Table S2A, Model 1–3).

Using age as the independent variable, fully adjusted models showed increasing systolic BP ($\beta = .7$, 95% CI: 0.5, 0.8), total cholesterol ($\beta = .03$, 95% CI: 0.02, 0.04), HDL ($\beta = .005$, 95% CI: 0.001, 0.009), LDL ($\beta = .025$, 95% CI: 0.02, 0.03), triglycerides ($\beta = .005$, 95% CI: 0.0008, 0.009), and IL-6 ($\beta = -.03$, 95% CI: −0.04, −0.01) with increasing age (Table 2).

3.3 | Reproductive stage versus chronologic age: Changes in cardiovascular risk factors across time (longitudinal analysis)

We examined the mean difference in CVD markers comparing women at baseline and follow-up in each group (Table S3A). Using linear mixed models for longitudinal analyses, fully corrected models did not show any statistically significant differences in 5-year changes on all cardiovascular risk factors comparing TRANS, EPOST and LPOST to PRE (Table 3). On the incremental addition of covariates (Table S3B), we found that medication-adjusted model (Model 1) showed higher cholesterol and LDL in early- and late postmenopausal women. There is also an increase in triglycerides in the menopause transition group compared to premenopausal women in medication-, age-, and lifestyle-adjusted models (Model 1–3).

Using age as the independent variable in the linear mixed models, we observed age to be associated with changes in cardiovascular risk factors. In particular, there was an increase in systolic BP ($\beta = .7$, 95% CI: 0.6, 0.8), diastolic BP ($\beta = .09$, 95% CI: 0.02, 0.16), total cholesterol ($\beta = .03$, 95% CI: 0.03, 0.04), HDL ($\beta = .006$, 95% CI: 0.003, 0.009), LDL ($\beta = .02$, 95% CI: 0.02, 0.03), triglycerides ($\beta = .006$, 95% CI: 0.003, 0.009), fasting glucose ($\beta = .006$, 95% CI: 0.002, 0.01), and adiponectin ($\beta = .008$, 95% CI: 0.003, 0.01) with increasing chronologic age (Table 3). Other inflammatory markers, IL-6 ($\beta = -.02$, 95% CI: −0.03, −0.006) and IL-1β ($\beta = -.02$, 95% CI: −0.03, −0.009), decreased with age.

TABLE 1 Baseline characteristics of women across different reproductive stages

	Premenopause (n = 696)	Transition (n = 463)	Early postmenopause (0–5 years) n = 164	Late postmenopause (≥5 years) N = 387	p Value[a]
Average follow-up time, years, mean (SD)	5.6 (0.5)	5.6 (0.5)	5.6 (0.5)	5.5 (0.4)	.313
Demographic and lifestyle factors					
Age, mean (SD)	40.7 (3.6)	47.2 (4.1)	53.2 (4.2)	62.5 (7.4)	<.001
Age at menopause onset, mean (SD)	–	–	50.7 (3.9)	47.8 (5.4)	<.001
Educational attainment (%)					
High	189 (27.2)	98 (21.2)	27 (16.5)	36 (9.3)	<.001
Middle	201 (28.9)	129 (27.9)	42 (25.6)	93 (24.0)	
Low	306 (43.9)	236 (50.9)	95 (57.9)	258 (66.7)	
Physical activity[b]					
None	197 (28.9)	168 (36.6)	65 (39.9)	135 (35.6)	<.001
1 per week	91 (13.3)	48 (10.5)	13 (8.0)	15 (4.0)	
2x per week	383 (56.2)	233 (50.8)	84 (51.5)	228 (60.2)	
>3 per week	11 (1.6)	10 (2.2)	1 (0.6)	1 (0.2)	
Drinker (%)	449 (64.5)	300 (64.8)	97 (59.2)	230 (59.4)	.215
Alcohol consumption (units/week)	3.7 (5.5)	4.2 (6.3)	3.4 (4.1)	3.7 (5.2)	.379
Smoking					
Current smoker (%)	186 (26.7)	143 (30.9)	36 (22.0)	93 (24.0)	.176
Former smoker (%)	183 (26.3)	127 (27.4)	47 (28.7)	104 (26.9)	
Never (%)	327 (47.0)	193 (41.7)	81 (49.3)	190 (49.1)	
Hypertension (%)	69 (9.9)	70 (15.1)	52 (31.7)	184 (47.6)	<.001
Use of antihypertensive	30 (4.3)	29 (6.3)	26 (15.9)	99 (25.6)	<.001
Diabetes (%)	5 (0.7)	6 (1.3)	6 (3.7)	38 (9.8)	<.001
Use of antidiabetic meds (%)	2 (0.3)	4 (0.9)	5 (3.1)	25 (6.5)	<.001
Baseline cardiovascular disease (%)	9 (1.3)	5 (1.1)	10 (6.1)	36 (9.3)	<.001
Use of statins (lipid lowering drugs) (%)	5 (0.7)	7 (1.5)	8 (4.9)	56 (14.5)	<.001
Body mass index (kg/m^2)	23.8 (4.3)	24.2 (4.4)	25.6 (5.2)	26.8 (5.4)	<.001
Blood pressure					
Systolic blood pressure (mmHg)	114.6 (12.4)	118.9 (14.8)	123.2 (16.5)	133.1 (19.6)	<.001
Diastolic blood pressure (mmHg)	74.6 (10.1)	76.7 (10.9)	78.4 (11.1)	80.1 (11.0)	<.001
Lipid profile					
Total cholesterol (mmol/L)	5.1 (0.8)	5.3 (0.9)	5.9 (1.0)	6.0 (1.0)	<.001
High-density lipoprotein (mmol/L)	1.8 (0.4)	1.8 (0.5)	1.8 (0.4)	1.8 (0.5)	.029
Low-density lipoprotein (mmol/L)	2.9 (0.7)	3.0 (0.8)	3.5 (0.9)	3.5 (0.9)	<.001
Triglycerides (mmol/L)[c]	0.95 (0.48)	1.02 (0.53)	1.12 (0.54)	1.37 (0.72)	<.001
Glucose metabolism					
Fasting glucose (mmol/L)	5.09 (0.74)	5.19 (0.59)	5.31 (0.86)	5.64 (1.38)	<.001
Insulin (micro IU/ml)[c]	7.27 (4.54)	7.08 (4.27)	7.37 (3.78)	9.35 (6.34)	<.001
Insulin resistance index[d]	1.68 (1.25)	1.66 (1.05)	1.81 (1.13)	2.48 (2.09)	<.001
Cardiovascular/inflammatory markers					
High sensitivity C-reactive protein (pg/ml)[c]	2.26 (3.52)	2.07 (3.09)	2.25 (3.35)	3.03 (3.94)	<.001

(Continues)

TABLE 1 (Continued)

	Premenopause ($n = 696$)	Transition ($n = 463$)	Early postmenopause (0–5 years) $n = 164$	Late postmenopause (≥5 years) $N = 387$	p Value[a]
Leptin (ng/ml)[c,e]	1.25 (0.90)	1.28 (0.96)	1.47 (0.99)	1.69 (1.10)	<.001
Adiponectin (ng/ml)[c,e]	1.19 (0.80)	1.17 (0.63)	1.51 (1.31)	1.38 (0.93)	<.001
Tumour necrosis factor-alpha (pg/ml)[c]	11.4 (131.6)	4.4 (11.0)	12.8 (96.6)	4.7 (13.4)	<.001
Interleukin-6 (pg/ml)[c]	9.27 (65.4)	18.5 (247.1)	10.8 (43.8)	10.3 (98.2)	.576
Interleukin-1β (pg/ml)[c]	5.64 (52.4)	4.15 (15.5)	6.27 (25.7)	2.58 (9.2)	.049
Framingham risk score[f]	2.32 (1.76)	3.94 (2.57)	6.37 (4.08)	10.92 (7.2)	<.001

[a]Analysis of variance for continuous variables and χ^2 test for categorical variables.

[b]Physical activity was obtained by self-report of doing physical activity for more than 20 min/day/week.

[c]Crude values. Transformation of values done in logarithmic scale before testing for statistical significance. Summary values expressed as median (interquartile range).

[d]Based on Homeostatic Model Assessment for Insulin Resistance, HOMA IR. (Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*. 1985;28:412-19).

[e]Converted to standardized scores (subtracting the assay values by the mean, and divided by the standard deviation).

[f]Framingham risk score computed only for women without a history of cardiovascular disease (PRE 687, TRANS 458, EPOST 256, LPOST 351) (Formula based on D'Agostino RB, Sr., Vasan RS, Pencina MJ, et al. Circulation. 2008 Feb 12;117(6):743-53).

3.4 | Sensitivity analyses

In comparison to women who were excluded from the study (Table S1A), women included in our study were younger (mean age: 48.6 ± 9.7 vs. 57.1 ± 9.9 years), with a higher proportion of current smokers (26.8% vs. 23.0%). We also noted a lower proportion of diabetes (3.2% vs. 4.7%) and hypertension (21.9% vs. 37.7%). The women included in the study had lower BMI, BPs, lipid profiles, glucose metabolism indices and cardiovascular/inflammatory markers compared to those excluded.

Upon restricting our analyses to specific groups of women (i.e., 1590 women with natural menopause, and 1213 women without comorbidities) in our cross-sectional analyses, our estimates were similar except when restricting to women without comorbidities (Table S2B). For women without comorbidities, early postmenopause had higher cholesterol and LDL compared to premenopausal women. Both early and postmenopausal women without comorbidities had higher adiponectin and IL-6 compared to premenopausal women. In our longitudinal analyses, early menopause women had higher total cholesterol compared to premenopausal women for those with no comorbidities ($\beta = 1.99$, 95% CI: 0.09, 3.9) (Table S3C). Furthermore, triglycerides were higher in the menopause transition group than premenopausal women upon restriction to those who had natural menopause ($\beta = .55$, 95% CI: 0.04, 1.1). Although, both comparisons did not reach statistical significance when adjusting for multiple testing.

We also explored our models by using time-varying covariates. Our longitudinal model showed higher triglyceride levels ($\beta = .52$, 95% CI: 0.001, 1.04) for the menopause transition group than premenopausal women considering changes in smoking and alcohol intake habits over time (Table S4).

Finally, to explore changes in cardiovascular risk in women with a larger sample size, we iterated all our models using 2558 women, including hormone therapy users. Results were in line with our main results (Tables S5–S7).

4 | DISCUSSION

Women in midlife experience dramatic hormonal, physiologic, psychologic and social changes. As women in midlife transition to menopause, previous studies have associated this critical period with increased cardiovascular risk. Ageing is the strongest predictor of cardiovascular risk. However, in women, this relationship is more complex because of their transitions through reproductive stages. Since chronologic age and reproductive stage are closely related, it is challenging to determine whether reproductive stage or cumulative ageing are more relevant to increased cardiovascular risk after menopause.

In cross-sectional analyses we observed a poorer cardiovascular risk factor profile among women in advanced reproductive stage (postmenopausal). While postmenopausal women still had the worst cardiovascular profile after 5 years of follow-up, the longitudinal changes in cardiovascular risk factors were similar across all reproductive stages. In our sensitivity analyses, we removed women with surgical- or chemotherapy-induced menopause as they carry higher cardiovascular risk due to their primary condition. The models did not result in statistically significant changes. On the other hand, age risk models showed statistically significant associations with cardiovascular risk factors even after adjusting for the reproductive stage. We surmise that age is still a stronger predictor of poorer cardiovascular risk than advancing reproductive stage.

TABLE 2 The association between chronologic age or reproductive stage with cardiovascular risk factors at baseline (using linear regression on fully corrected models, expressed as beta coefficients and 95% confidence interval)

Cardiovascular risk factors	Chronologic age[a]	Reproductive stage[b]			
		Premenopause (PRE)	Transition (TRANS)	Early menopause (EPOST)	Late menopause (LPOST)
Body mass index (kg/m^2)	0.099 (−0.144, 0.343)	Ref	0.542 (−0.042, 1.128)	**1.451 (0.537, 2.365)**	**2.361 (1.277, 3.444)**
Blood pressure					
Systolic blood pressure (mmHg)	**0.671 (0.529, 0.812)**	Ref	*−0.463 (−2.358, 1.432)*	*−2.597 (−5.563, 0.368)*	*−0.267 (−3.797, 3.262)*
Diastolic blood pressure (mmHg)	0.043 (−0.056, 0.143)	Ref	**1.542 (0.205, 2.881)**	1.322 (−0.771, 3.416)	1.793 (−0.699, 4.285)
Lipid profile					
Total cholesterol (mmol/L)	**0.032 (0.023, 0.041)**	Ref	0.054 (−0.066, 0.174)	**0.388 (0.201, 0.576)**	**0.248 (0.024, 0.471)**
High-density lipoprotein (mmol/L)	**0.005 (0.001, 0.009)**	Ref	0.044 (−0.005, 0.094)	**0.087 (0.010, 0.165)**	0.015 (−0.077, 0.108)
Low-density lipoprotein (mmol/L)	**0.025 (0.017, 0.033)**	Ref	*−0.003 (−0.112, 0.106)*	**0.290 (0.119, 0.461)**	0.161 (−0.041, 0.364)
Triglycerides (mmol/L)[c]	**0.005 (0.0008, 0.009)**	Ref	0.019 (−0.037, 0.075)	0.029 (−0.058, 0.117)	**0.125 (0.021, 0.230)**
Glucose metabolism					
Fasting glucose (mmol/L)	0.0017 (−0.005, 0.008)	Ref	0.075 (−0.016, 0.166)	0.081 (−0.061, 0.224)	**0.202 (0.032, 0.371)**
Insulin (micro IU/ml)[c]	*−0.002 (−0.007, 0.003)*	Ref	*−0.041 (−0.116, 0.033)*	*−0.052 (−0.168, 0.064)*	0.104 (−0.033, 0.241)
Insulin resistance index[c,d]	*−0.001 (−0.007, 0.004)*	Ref	*−0.021 (−0.100, 0.056)*	*−0.036 (−0.158, 0.086)*	0.139 (−0.004, 0.283)
Cardiovascular/inflammatory markers					
High sensitivity C-reactive protein[c]	*−0.001 (−0.011, 0.009)*	Ref	*−0.031 (−0.123, 0.060)*	*−0.023 (−0.151, 0.106)*	**0.181 (0.034, 0.329)**
Leptin (ng/ml)[c,e]	*-0.018 (−0.052, 0.016)*	Ref	0.007 (−0.076, 0.091)	0.102 (−0.027, 0.230)	**0.184 (0.030, 0.338)**
Adiponectin (ng/ml)[c,e]	0.004 (−0.0019, 0.0107)	Ref	0.015 (−0.070, 0.099)	**0.223 (0.094, 0.353)**	**0.213 (0.057, 0.369)**
Tumour necrosis factor-alpha (pg/ml)[c]	*−0.002 (−0.011, 0.007)*	Ref	*−0.004 (−0.130, 0.123)*	0.146 (−0.050, 0.343)	0.067 (−0.169, 0.303)
Interleukin-6 (pg/ml)[c]	***−0.027 (−0.042, −0.012)***	Ref	**0.216 (0.008, 0.424)**	**0.410 (0.093, 0.729)**	**0.532 (0.146, 0.919)**
Interleukin-1β (pg/ml)[c]	*−0.009 (−0.029, 0.009)*	Ref	*−0.110 (−0.363, 0.142)*	0.155 (−0.242, 0.553)	*−0.143 (−0.619, 0.333)*

[a]Beta coefficients based on multivariate linear regression on fully corrected models (*italicized for negative beta coefficient*, *p < .05 in bold, corrected for use of hypoglycaemia drugs, statins and antihypertensive drugs, smoking history, alcohol-use, baseline physical activity, baseline cardiovascular disease and body mass index).

[b]Beta coefficients based on multivariate linear regression on fully corrected models (*italicized for negative beta coefficient*, *p < .05 in bold, corrected for use of hypoglycaemia drugs, statins and antihypertensive drugs, age, smoking history, alcohol-use, baseline physical activity, baseline cardiovascular disease and body mass index).

[c]Transformation of values done in logarithmic scale before testing for statistical significance.

[d]Based on Homeostatic Model Assessment for Insulin Resistance, HOMA IR.

[e]Converted to standardized scores (subtracting the assay values by the mean, and divided by the standard deviation).

TABLE 3 Changes in intermediate cardiovascular with chronologic age or reproductive stage over time (using linear mixed models regression on fully corrected models, expressed as beta coefficients and 95% confidence interval)

Cardiovascular risk factors	Chronologic age[a]	Reproductive stage[b]		
		Premenopause (PRE)	Transition (TRANS)	Early menopause (EPOST)	Late menopause (LPOST)
Body mass index (kg/m^2)	*−0.014 (−0.049, 0.021)*	Ref	3.882 (−2.050, 9.815)	1.494 (−5.604, 8.591)	0.324 (−4.795, 5.443)
Blood pressure					
Systolic blood pressure (mmHg)	**0.716 (0.612, 0.820)**	Ref	*−2.472 (−20.09, 15.14)*	*−7.451 (−30.57, 15.67)*	*−6.039 (−26.74, 14.66)*
Diastolic blood pressure (mmHg)	**0.087 (0.015, 0.159)**	Ref	1.139 (−11.07, 13.358)	*−1.107 (−17.14, 14.93)*	*−2.413 (−16.76, 11.93)*
Lipid profile					
Total cholesterol (mmol/L)	**0.031 (0.025, 0.038)**	Ref	0.445 (−0.683, 1.594)	1.442 (−0.054, 2.939)	0.853 (−0.471, 2.179)
High-density lipoprotein (mmol/L)	**0.006 (0.003, 0.009)**	Ref	−0.231 (−0.728, 0.266)	0.009 (−0.644, 0.664)	0.0164 (−0.562, 0.595)
Low-density lipoprotein (mmol/L)	**0.022 (0.016, 0.029)**	Ref	0.425 (−0.611, 1.462)	1.215 (−0.147, 2.577)	0.756 (−0.450, 1.963)
Triglycerides (mmol/L)[c]	**0.006 (0.003, 0.009)**	Ref	0.513 (−0.004, 1.031)	0.513 (−0.004, 1.031)	0.325 (−0.276, 0.928)
Glucose metabolism					
Fasting glucose (mmol/L)	**0.006 (0.002, 0.011)**	Ref	0.308 (−0.455, 1.072)	*−0.251 (−1.255, 0.753)*	*−0.194 (−1.082, 0.695)*
Insulin (micro IU/ml)[c]	0.001 (−0.002, 0.005)	Ref	*−0.174 (−0.784, 0.437)*	*−0.379 (−1.176, 0.418)*	*−0.305 (−0.988, 0.378)*
Insulin resistance index[c,d]	0.002 (−0.001 0.006)	Ref	*−0.105 (−0.753, 0.543)*	*−0.428 (−1.274, 0.418)*	*−0.320 (−1.044, 0.403)*
Cardiovascular/inflammatory markers					
High sensitivity C-reactive protein[c]	0.0005 (−0.006, 0.007)	Ref	0.199 (−1.035, 1.435)	*−1.083 (−2.693, 0.526)*	*−0.227 (−1.662, 1.206)*
Leptin (ng/ml)[c,e]	*−0.002 (−0.008, 0.003)*	Ref	0.241 (−0.791, 1.273)	0.778 (−0.519, 2.075)	0.273 (−0.873, 1.419)
Adiponectin (ng/ml[c,e]	**0.008 (0.003, 0.012)**	Ref	*−0.330 (−1.007, 0.440)*	0.403 (−0.588, 1.392)	0.110 (−0.745, 0.965)
Tumour necrosis factor-alpha (pg/ml)[c]	0.0010 (−0.006, 0.008)	Ref	*−0.025 (−1.188, 1.137)*	*−0.00,154 (−1.477, 1.474)*	0.461 (−0.863, 1.785)
Interleukin-6 (pg/ml)[c]	***−0.017 (−0.028, −0.006)***	Ref	0.206 (−1.726, 2.138)	*−0.511 (−2.958, 1.937)*	*−1.296 (−3.494, 0.901)*
Interleukin-1β (pg/ml)[c]	***−0.020 (−0.032, −0.009)***	Ref	0.529 (−1.412, 2.471)	*−0.502 (−3.008, 2.004)*	0.481 (−1.759, 2.722)

[a]Beta coefficients based on multivariate linear regression on fully corrected models (*italicized for negative beta coefficient* *$p < .05$ in bold, corrected for reproductive stage, use of hypoglycaemia drugs, statins and antihypertensive, smoking history, alcohol-use, baseline physical activity, baseline cardiovascular disease, body mass index and menopause status at baseline and follow up).

[b]Beta coefficients based on multivariate linear regression on fully corrected models (*italicized for negative beta coefficient*, *$p < .05$ in bold, corrected for use of hypoglycaemia drugs, statins and antihypertensives, age, smoking history, alcohol-use, baseline physical activity, baseline cardiovascular disease and body mass index at baseline and follow-up).

[c]Transformation of values done in logarithmic scale before testing for statistical significance.

[d]Based on Homeostatic Model Assessment for Insulin Resistance, HOMA IR.

[e]Converted to standardized scores (subtracting the assay values by the mean, and divided by the standard deviation).

Cross-sectional analyses investigating the role of the reproductive stage in cardiovascular risk factors have unanimously identified a poorer CVD risk profile in postmenopausal compared to premenopausal women.[19–23] Our findings reiterate these findings. CVDs result from accumulated stress on several pathways that ultimately lead to vascular damage and heart disease. However, the clinical profiles of premenopausal and postmenopausal women within the same age range are different and incomparable. Women of the same age with different reproductive stages are deemed to have different health status and lifestyle that confounds their cardiovascular risks. Also, the directionality of the variables (cause and effect) is something that the cross-sectional analysis cannot resolve. Thus, cross-sectional study designs are inherently limited in resolving this issue.

Longitudinal analyses allow one to follow through with each subject and consider variability among women with a reproductive stage, and variability between stages. More importantly, the direction of causality can only be determined through this study design. To our knowledge, only a few studies used this approach,[25–29] and far fewer were done in Europe.[27] Body composition was studied in two analyses with divergent results.[28,29] One study demonstrated an increased fat mass seen in advanced reproductive stage,[29] but no difference was seen in another study.[28] Our study was limited to BMI, for which we observed no significant changes across different reproductive stages. Various longitudinal studies were consistent on the association of older reproductive stage and poorer lipid profile, although there was incoherence as to which specific lipid molecule. In a women's cohort in Australia with 150 participants, the longitudinal analysis showed a difference with the older reproductive stage (postmenopause). These women underwent repeated measures across 7 years of observation as they transitioned to menopause. HDL was lower in the postmenopausal phase compared to the premenopausal phase of their reproductive life.[25] In another women's cohort in the United States with 1054 participants compared across different reproductive stage groups, Matthews et al.[26] reported total cholesterol, apoB, and LDL were higher in the menopause transition. We did not find any statistically significant difference in changes in serum lipids across different reproductive stages on our fully adjusted models. In our sensitivity analyses, we found triglycerides levels were higher for women in menopause transition in medication-, age-, and lifestyle-adjusted models than the premenopausal women (Table S3B, Model 1–3). Cholesterol and LDL were also higher in early and late postmenopausal group than the premenopausal group only in the medication-adjusted model (Table S3B, Model 1). However, owing to multiple comparisons, it is highly possible that these are merely chance findings with limited clinical significance.

Most cross-sectional data consistently showed a higher prevalence of diabetes in postmenopausal compared to the premenopausal group.[34–36] However, the ageing trajectory is rarely considered or treated inappropriately in all these studies. Our findings are consistent with other menopause longitudinal studies showing no significant changes among different reproductive stages.[26,37] Thus, menopause, per se, seems to be less important, and the ageing process and other lifestyle factors are still dominant factors in the development of diabetes. A systematic review has found that postmenopausal obesity influences the development of diabetes,[38] therefore, highlighting the importance of lifestyle modification during menopause transition and thereafter.

IL-6 and IL-1β are inflammatory markers that are known to be higher in the ageing population.[39] Both are proinflammatory cytokines that are sometimes used as markers of chronic disease and frailty in the elderly.[40,41] Our analysis showed no significant changes in IL-6 and IL-1β according to the reproductive stage but we report inverse association (decreases) with age. Changes in laboratory standards across time, selection bias towards the healthy group, and missing data could have led our results to an opposite trend. Nevertheless, these finding warrants to be investigated further.

Our study has important differences in the study design and analysis compared to the other women's health studies. We assumed a linear relationship, used two-time points with a 5.5 (±0.4) year interval, and specified premenopausal women as the comparison group. The Study of Women's Health Across the Nation (SWAN) in the United States and the Melbourne Women's Midlife Health Project in Australia both used piecewise regression (and explored nonlinear relationship), used multiple data points across time, and used menopause transition as a reference. These crucial differences could be the main reason for the disparity of our results to these women's cohorts.

The normal ageing process in women is accompanied not only by a decline in ovarian function but also by changes in epigenetic profile, increased oxidative damages, and varied iron metabolism. All these are known to contribute to elevated cardiovascular risk profiles in ageing women. For example, the changes in sex hormones accompanying menopause affect the baseline chronic inflammation, endothelial function and serum lipid levels, which puts them at higher risk for CVD.[42] However, genetic variations and epigenetic changes that are related to early-onset menopause had been discovered to be associated with increased cardiovascular risk factors.[43] Also, ageing is associated with the accumulation of oxidative stress, one of the main drivers of heightened risk, independent of menopause status. Together, all these factors make it challenging to associate whether menopause alone is an independent risk factor for CVD.

4.1 | Strengths and weaknesses

The onset of menopause has been largely affected by region and ethnicity. External and other environmental factors such as diet, physical activity, smoking, mental health and socioeconomic factors influence the menopause onset. We present one of the few studies from a cohort of women in Europe, with a growing ageing population, and thus, at a high burden of CVDs. This is with a background of varying menopausal ages and practices in hormone replacement therapy in European compared to North American women cohorts that may significantly affect the cardiovascular risk. Europeans have a

better dietary pattern, higher physical activity, and better health-seeking behaviour than in the United States.[44,45] Women in Switzerland, and Europe in general, have higher rates of smokers compared to women in the other cohorts.[46] Our cohort had 53.9% (923/1710) women who never smoked, which is higher compared to SWAN cohort in the United States (42.7%)[26] and to Melbourne Womens' Health in Australia (22%).[25,47,48] Also, our study is one of the largest longitudinal analyses in terms of sample size and has a lower dropout rate compared to other cohorts that have longitudinal data on reproductive stage and cardiovascular risk factors[26,49–53] Lastly, we analysed inflammatory markers utilized in cardiovascular risk stratification, which were reported in few cohorts.[26,27]

However, our study has important limitations that merit to be discussed. First, the included participants had more favourable lifestyle and cardiovascular risk factor profiles compared to the excluded (Table S1A). Our study population had higher baseline physical activity levels, lower proportion of smokers and higher educational attainment. All of which could point to a bias similar to healthy users or adherers. This is a common bias in observational studies when individuals with healthier lifestyles have higher participation rates than nonparticipants or those lost to follow-up. A selection bias towards the healthy individuals could have been the reason for our null findings or finding no statistically significant difference among different reproductive stages across time. As a result, our results on CVD risk factors prevalence across different reproductive stages might have been underestimated. The true differences between reproductive stages may be revealed if women with poorer lifestyles were included. Second, our exposure classification (menstruation status) is based on self-reported data. Women were classified into reproductive stage groups based on the baseline questionnaire, and the status was confirmed using self-reported age at last menstruation. Also, there was no active follow-up on the women between the 5-year gaps to confirm the menstrual status. We did the necessary counterchecks to confirm the menstruation status of the women in our cohort. All women with invalid responses to menopause were removed from the analysis. With the erroneous response rate (as mentioned in the methods), we surmise that up to 5% of the women may have been misclassified in our analysis and would be unlikely to change our estimates dramatically. Third, focusing on a specific population can remove other confounding factors, but this also raises the question of the generalizability of results with women of different ethnicities. Fourth, our laboratory assays were done in real-time between baseline and follow-up, and not simultaneously performed on biobank blood samples. Although all samples were processed by one laboratory (CHUV), the laboratory standards could have changed across the period, and these were not accounted for in our models. Fifth, women who underwent hysterectomy, oophorectomy, and chemotherapy were all classified as nonnatural menopause. Women who underwent hysterectomy with preserved ovaries are a particular group of women with different endocrinologic profiles than those who underwent oophorectomy (ovaries removed). Unfortunately, our data was not able to distinguish these two groups, and we iterated our models on women with natural menopause. Finally, we only compared two data points to characterize the early changes in cardiovascular risk factors. We expect a more optimized model that would likely capture the true effects by increasing the data points. Corollary to this, we also assumed that associations are mostly linear, which is different from some studies that performed a piecewise linear regression model (over multiple time points) and performed spline modelling.[26]

4.2 | Future direction and outlook

Women in menopausal transition are a particular phenotype as the body begins to experience hormonal changes (reproductive stage) and advancing age (chronologic age). Studies have shown that women in the transition phase of menopause have higher cardiovascular risk factors (i.e., lipid profile, glucose, BP, fat composition), and a longitudinal analysis had further strengthened the influence of the reproductive stage on lipid profile. However, women in the transition phase are not being targeted by current clinical guidelines on CVD prevention. This is likely due to the absence of universally accepted reproductive ageing criteria that are in use by healthcare providers, and thus, precluding preventive care to this group. Currently, there is no validated biomarker that aids in the classification or a widely accepted scoring system in determining those at the transition phase of menopause.[54] The *sine qua non* for the diagnosis, and the operational definition of menopause remain the absence of menstrual bleeding for a year. More research is needed to look for biomarkers in aid of classification. More longitudinal studies on biomarkers for ovarian age are still lacking.

Aside from a standard classification of reproductive stage, there is still a considerable discussion over menopause and sex hormones' effect on women's cardiovascular health. As of now, there is no large women's cohort in Europe with detailed information on their reproductive and menstrual history, combined with biomarkers and genetic information. The cohorts in North America have driven much of our current knowledge, although with different dietary patterns, lifestyle habits and genetic predispositions. Lastly, there is a need for more longitudinal studies accounting for the natural ageing process and, most importantly, explain the directionality and causality of cardiovascular risk differences.

5 | CONCLUSION

All women increase their cardiovascular risk as they get older, and in our study, we found no differences in cardiovascular risk changes comparing women in advanced reproductive stages with premenopausal women. This highlights the strong association between chronological age and the cumulative deleterious effects in CVD risk for women. More longitudinal studies that use novel biomarkers for ovarian age are still needed to disentangle the association between menopause and CVD risk in postmenopausal women and women in the menopause transition. Although the proof of menopause and the menopause transition is still lacking, it would be prudent to do screening and preventive measures during menopause transition as

these are also ageing women with inherent cardiovascular risks. Cardiovascular preventive measures should target not only post-menopausal women but also women in the transition phase while waiting for more conclusive evidence.

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are not publicly available. Information related to data access can be made available to interested researchers at https://www.colaus-psycolaus.ch/professionals/how-to-collaborate/.

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REFERENCES

1. Davis SR, Lambrinoudaki I, Lumsden M, et al. Menopause. *Nat Rev Dis Primers*. 2015;1:15004.
2. Gold EB. The timing of the age at which natural menopause occurs. *Obstet Gynecol Clin North Am*. 2011;38(3):425-440.
3. Zhu D, Chung HF, Dobson AJ, et al. Age at natural menopause and risk of incident cardiovascular disease: a pooled analysis of individual patient data. *Lancet Public Health*. 2019;4(11):E553-E564.
4. Armeni E, Lambrinoudaki I, Ceausu I, et al. Maintaining postreproductive health: a care pathway from the European Menopause and Andropause Society (EMAS). *Maturitas*. 2016;89:63-72.
5. Dudley EC, Hopper JL, Taffe J, Guthrie JR, Burger HG, Dennerstein L. Using longitudinal data to define the perimenopause by menstrual cycle characteristics. *Climacteric*. 1998;1(1):18-25.
6. Kwaśniewska M, Pikala M, Kaczmarczyk-Chałas K, et al. Smoking status, the menopausal transition, and metabolic syndrome in women. *Menopause*. 2012;19(2):194-201.
7. Gast GC, Grobbee DE, Pop VJ, et al. Menopausal complaints are associated with cardiovascular risk factors. *Hypertension*. 2008;51(6):1492-1498.
8. Thurston RC, El Khoudary SR, Sutton-Tyrrell K, et al. Vasomotor symptoms and insulin resistance in the Study of Women's Health Across the Nation. *J Clin Endocrinol Metab*. 2012;97(10):3487-3494.
9. Atsma F, Bartelink ML, Grobbee DE, van der Schouw YT. Postmenopausal status and early menopause as independent risk factors for cardiovascular disease: a meta-analysis. *Menopause*. 2006;13(2):265-279.
10. Thurston RC, Johnson BD, Shufelt CL, et al. Menopausal symptoms and cardiovascular disease mortality in the Women's Ischemia Syndrome Evaluation (WISE). *Menopause*. 2017;24(2):126-132.
11. Szmuilowicz ED, Manson JE, Rossouw JE, et al. Vasomotor symptoms and cardiovascular events in postmenopausal women. *Menopause*. 2011;18(6):603-610.
12. Janssen I, Powell LH, Crawford S, Lasley B, Sutton-Tyrrell K. Menopause and the metabolic syndrome: the Study of Women's Health Across the Nation. *Arch Intern Med*. 2008;168(14):1568-1575.
13. Gohlke-Bärwolf C. Coronary artery disease—is menopause a risk factor? *Basic Res Cardiol*. 2000;95(1):I77-I83.
14. Auro K, Joensuu A, Fischer K, et al. A metabolic view on menopause and ageing. *Nat Commun*. 2014;5:4708.
15. El Khoudary SR, Aggarwal B, Beckie TM, et al. Menopause transition and cardiovascular disease risk: implications for timing of early prevention: a scientific statement from the American Heart Association. *Circulation*. 2020;142(25):e506-e532.
16. Maas A, Rosano G, Cifkova R, et al. Cardiovascular health after menopause transition, pregnancy disorders, and other gynaecologic conditions: a consensus document from European cardiologists, gynaecologists, and endocrinologists. *Eur Heart J*. 2021;42(10):967-984.
17. Patrelli TS, Gizzo S, Franchi L, et al. A prospective, case-control study on the lipid profile and the cardiovascular risk of menopausal women on oestrogen plus progestogen therapy in a northern Italy province. *Arch Gynecol Obstet*. 2013;288(1):91-97.
18. Stefanska A, Sypniewska G, Senterkiewicz L. Inflammatory markers and cardiovascular risk in healthy Polish women across the menopausal transition. *Clin Chem*. 2005;51(10):1893-1895.
19. Stevenson JC, Crook D, Godsland IF. Influence of age and menopause on serum lipids and lipoproteins in healthy women. *Atherosclerosis*. 1993;98(1):83-90.
20. Cho GJ, Lee JH, Park HT, et al. Postmenopausal status according to years since menopause as an independent risk factor for the metabolic syndrome. *Menopause*. 2008;15(3):524-529.
21. Peters HW, Westendorp IC, Hak AE, et al. Menopausal status and risk factors for cardiovascular disease. *J Intern Med*. 1999;246(6):521-528.
22. Pansini F, Bonaccorsi G, Calisesi M, et al. Influence of spontaneous and surgical menopause on atherogenic metabolic risk. *Maturitas*. 1993;17(3):181-190.
23. de Kat AC, Dam V, Onland-Moret NC, Eijkemans MJ, Broekmans FJ, van der Schouw YT. Unraveling the associations of age and menopause with cardiovascular risk factors in a large population-based study. *BMC Med*. 2017;15(1):2.
24. Otsuki M, Kasayama S, Morita S, et al. Menopause, but not age, is an independent risk factor for fasting plasma glucose levels in nondiabetic women. *Menopause*. 2007;14(3 Pt 1):404-407.
25. Do KA, Green A, Guthrie JR, Dudley EC, Burger HG, Dennerstein L. Longitudinal study of risk factors for coronary heart disease across the menopausal transition. *Am J Epidemiol*. 2000;151(6):584-593.
26. Matthews KA, Crawford SL, Chae CU, et al. Are changes in cardiovascular disease risk factors in midlife women due to chronological aging or to the menopausal transition? *J Am Coll Cardiol*. 2009;54(25):2366-2373.
27. Karvinen S, Jergenson MJ, Hyvärinen M, et al. Menopausal status and physical activity are independently associated with cardiovascular risk factors of healthy middle-aged women: cross-sectional and longitudinal evidence. *Front Endocrinol*. 2019;10:589.

28. Sowers M, Zheng H, Tomey K, et al. Changes in body composition in women over six years at midlife: ovarian and chronological aging. *J Clin Endocrinol Metab*. 2007;92(3):895-901.
29. Razmjou S, Abdulnour J, Bastard JP, et al. Body composition, cardiometabolic risk factors, physical activity, and inflammatory markers in premenopausal women after a 10-year follow-up: a MONET study. *Menopause*. 2018;25(1):89-97.
30. Firmann M, Mayor V, Vidal PM, et al. The CoLaus study: a population-based study to investigate the epidemiology and genetic determinants of cardiovascular risk factors and metabolic syndrome. *BMC Cardiovasc Disord*. 2008;8:6.
31. Marques-Vidal P, Waeber G, Vollenweider P, Bochud M, Stringhini S, Guessous I. Sociodemographic and behavioural determinants of a healthy diet in Switzerland. *Ann Nutr Metab*. 2015;67(2):87-95.
32. D'Agostino RB Sr., Vasan RS, Pencina MJ, et al. General cardiovascular risk profile for use in primary care: the Framingham Heart Study. *Circulation*. 2008;117(6):743-753.
33. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia*. 1985;28(7):412-419.
34. Li Q, Wang X, Ni Y, et al. Epidemiological characteristics and risk factors of T2DM in Chinese premenopausal and postmenopausal women. *Lipids Health Dis*. 2019;18(1):155.
35. Heianza Y, Arase Y, Kodama S, et al. Effect of postmenopausal status and age at menopause on type 2 diabetes and prediabetes in Japanese individuals: Toranomon Hospital Health Management Center Study 17 (TOPICS 17). *Diabetes Care*. 2013;36(12):4007-4014.
36. Di Donato P, Giulini NA, Bacchi Modena A, et al. Risk factors for type 2 diabetes in women attending menopause clinics in Italy: a cross-sectional study. *Climacteric*. 2005;8(3):287-293.
37. Guthrie JR, Ball M, Dudley EC, et al. Impaired fasting glycaemia in middle-aged women: a prospective study. *Int J Obes Relat Metab Disord*. 2001;25(5):646-651.
38. Jiang J, Cui J, Wang A, et al. Association between age at natural menopause and risk of type 2 diabetes in postmenopausal women with and without obesity. *J Clin Endocrinol Metab*. 2019;104(7):3039-3048.
39. Rea IM, Gibson DS, McGilligan V, McNerlan SE, Alexander HD, Ross OA. Age and age-related diseases: role of inflammation triggers and cytokines. *Front Immunol*. 2018;9:586.
40. Ershler WB. Interleukin-6: a cytokine for gerontolgists. *J Am Geriatr Soc*. 1993;41(2):176-181.
41. Cavallone L. The role of IL-1 gene cluster in longevity: a study in Italian population. *Mech Ageing Dev*. 2003;124(4):533-538.
42. Xing D, Nozell S, Chen YF, Hage F, Oparil S. Estrogen and mechanisms of vascular protection. *Arterioscler Thromb Vasc Biol*. 2009;29(3):289-295.
43. Sarnowski C, Kavousi M, Isaacs S, et al. Genetic variants associated with earlier age at menopause increase the risk of cardiovascular events in women. *Menopause*. 2018;25(4):451-457.
44. Nichols M, Townsend N, Scarborough P, Rayner M. Cardiovascular disease in Europe: epidemiological update. *Eur Heart J*. 2013;34(39):3028-3034.
45. Grasgruber P, Cacek J, Hrazdíra E, Hřebíčková S, Sebera M. Global correlates of cardiovascular risk: a comparison of 158 countries. *Nutrients*. 2018;10(4):411.
46. Jafari A, Rajabi A, Gholian-Aval M, Peyman N, Mahdizadeh M, Tehrani H. National, regional, and global prevalence of cigarette smoking among women/females in the general population: a systematic review and meta-analysis. *Environ Health Prev Med*. 2021;26(1):5.
47. Shelley JM, Green A, Smith AM, et al. Relationship of endogenous sex hormones to lipids and blood pressure in mid-aged women. *Ann Epidemiol*. 1998;8(1):39-45.
48. Burger HG, Dudley EC, Hopper JL, et al. The endocrinology of the menopausal transition: a cross-sectional study of a population-based sample. *J Clin Endocrinol Metab*. 1995;80(12):3537-3545.
49. Tchernof A, Calles-Escandon J, Sites CK, Poehlman ET. Menopause, central body fatness, and insulin resistance: effects of hormone-replacement therapy. *Coron Artery Dis*. 1998;9(8):503-511.
50. Abdulnour J, Doucet E, Brochu M, et al. The effect of the menopausal transition on body composition and cardiometabolic risk factors: a Montreal-Ottawa New Emerging Team group study. *Menopause*. 2012;19(7):760-767.
51. Guthrie JR, Dennerstein L, Taffe JR, Lehert P, Burger HG. The menopausal transition: a 9-year prospective population-based study. The Melbourne Women's Midlife Health Project. *Climacteric*. 2004;7(4):375-389.
52. van der Leeuw J, Wassink AM, van der Graaf Y, Westerveld HE, Visseren FL. Age-related differences in abdominal fat distribution in premenopausal and postmenopausal women with cardiovascular disease. *Menopause*. 2013;20(4):409-417.
53. Lovejoy JC, Champagne CM, de Jonge L, Xie H, Smith SR. Increased visceral fat and decreased energy expenditure during the menopausal transition. *Int J Obes*. 2008;32(6):949-958.
54. Roa-Díaz ZM, Raguindin PF, Bano A, Laine JE, Muka T, Glisic M. Menopause and cardiometabolic diseases: what we (don't) know and why it matters. *Maturitas*. 2021;152:48-56.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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