Anthropological Review • Vol. 87(1), 33–51 (2024)

ANTHROPOLOGICAL REVIEW

Available online at: https://doi.org/10.18778/1898-6773.87.1.03

The variability of anthropometric and body composition parameters in middle-aged women associated with menopause and smoking

Simona Sulis, *Petra Švábová*

Department of Anthropology, Faculty of Natural Sciences, Comenius University in Bratislava, Bratislava, Slovakia

ABSTRACT: Menopause and its related hormonal changes are associated with the variation of body composition, especially impacting adipose tissue metabolism and the reduction of lean mass. The purpose of the present study was to investigate the impact of smoking during menopause on the subsequent effects on body composition.

The sample comprised of 572 Slovak women aged between 39 and 65 years (49.67±6.2). Standard anthropometric techniques were used to collect anthropometric measurements, whereas bioelectrical parameters were measured utilizing a mono-frequency bioimpedance analyzer (BIA 101). Data on menopausal status, physical activity, and smoking habits were obtained via a specific questionnaire.

In postmenopausal women, our results showed a statistically significant difference between smokers and non-smokers in BMI, TBW%, ECW%, ICW%, MM%, FFM%, FM% ($p < 0.05$). No significant differences were observed in premenopausal women, although two-way analysis of covariance revealed a significant interaction between smoking and menopausal status on the FM% ($p < 0.001$), FFM% ($p < 0.001$), and MM% ($p = 0.002$), whilst controlling for age and physical activity.

In our sample group of middle-aged women, the combined impact of menopause and smoking appeared to influence anthropometric parameters and body composition.

KEY WORDS: Body composition, physical health, aging, physical activity, smoking.

Original article

Received: 24.11.2023; Revised: 28.02.2024; Accepted: 04.03.2024

Introduction

Numerous factors, such as aging, health status, gender, genetic predisposition, and reproductive history influence body composition, which can be evaluated using anthropometric parameters such as body mass index (BMI), waist-to-hip ratio (WHR), as well as bioelectric impedance analysis (BIA) (Luptáková et al. 2013; Drozdová et al. 2016; Danková et al. 2017; Falbová et al. 2019; Vorobeľová et al. 2021, 2022). Compared to other techniques, BIA is a low-cost, readily accessible method which does not cause radiation exposure. The parameters collected and derived from BIA are the phase angle (PhA), reactance (Xc), resistance (R), fat mass (FM), fat-free mass (FFM), muscle mass (MM), and total body water (TBW) (Marini et al. 2020). Aging is one of the main determinants of body composition changes; part of this natural process in women is menopause, diagnosed after 12 months of amenorrhea with permanent termination of ovary functions (Greendale et al. 1999). Menopause is reportedly linked to an increase in BMI and body weight, specifically visceral fat mass (Donato et al. 2006; Dmitruk et al. 2018; Dehghan et al. 2021); the underlying cause is, however, still debated (Al-Safi and Polotsky 2015; Karvonen-Gutierrez and Kim 2016). These changes lead to the presentation of health conditions, such as metabolic syndrome and cardiovascular diseases (Matvienko et al. 2011; Opoku et al. 2023). Lovejoy et al. (2008) suggested that it is caused by lower energy expenditure and a decline in estrogen levels; others supported a similar hypothesis by documenting a rise of abdominal fat in response to hormonal changes (Svendsen et al. 1995; Kodoth et al. 2022) as reported by a 5-years prospective study where women who mitigated the decline of estrogen levels by using continuous hormone therapy did not experience weight gain (Guthrie et al. 1999). In a more recent study, Kwok et al. (2012) did not find an interaction between smoking and hormone activity (and smoking) on waist circumference and WHR while other studies have attributed an increase in BMI and obesity only to aging and not menopause (Trikudanathan et al. 2013; Greendale et al. 2019; Fenton 2021). Other changes in body composition associated with menopause include a reduction of lean mass (Sipilä et al. 2020), skeletal muscle mass, and total body water (Dmitruk et al. 2018). A factor closely related to obesity is a lack of physical activity, whereby its effects are amplified in postmenopausal women already impacted by aging and hormonal changes (Dubnov et al. 2003). A combination of abdominal adiposity, physical inactivity, and inflammatory markers have been related to sarcopenia (Maltais et al. 2009) while performing physical activity is crucial in preserving good health status in postmenopausal women. Physical activity not only has a profound effect on body composition by improving fat distribution (as reported by numerous studies conducted on women after menopause; Bendinelli et al. 2022; Juppi et al. 2022; Harraqui et al. 2023), but it also reduces mortality rates (Sherman et al. 1999). The positive effects of exercise in aging women are not limited to better fat distribution but also to improved FFM and skeletal MM, as reported by a study on a sample of Caucasian women conducted in Portugal who performed 12 months of a combination of step aerobics, muscle strength building and flexibility/postural control training (Aragão et al. 2014). Furthermore, according to a meta-analysis, high-intensity training, specifically cycling, benefits aging women's body composition (Dupuit et al. 2020). In contrast, it has been reported that smoking harms human health by increasing the risk of developing numerous maladies, such as cardiovascular diseases and cancer (Dai et al. 2022). Smoking also correlates with the prevalence of metabolic disorders and central obesity (Kwaśniewska et al. 2012), hence, smokers tend to have higher visceral fat mass and WHR than non-smokers (Falbová et al. 2023). Interestingly, smokers have also been observed to have a lower mean BMI compared to non-smokers due to an increased metabolic rate; this phenomenon has been reported in numerous cross-sectional and observational studies (Canoy et al. 2005; Clair et al. 2011; Efendi et al. 2018). However, after adjusting for confounding factors, other studies have reported no difference in fat mass between former smokers and persons who have never smoked (Akbartabartoori et al. 2005; Kim et al. 2012; Piirtola et al. 2018) providing further evidence regarding an increase in BMI due to quitting smoking. Specifically, in postmenopausal women who stopped smoking, the increase in fat mass and weight was associated with a higher muscle mass (Kleppinger et al. 2010). Moreover, among those trying to stop smoking women appeared to gain more weight compared to men, especially among older women compared to younger ones (McVay and Copeland 2011; Kasteridis and Yen 2012; Allen et al. 2014). In addition, an association between smoking and body composition has been reported by a cross-sectional study showing that after the cessation of smoking, BMI and FM increased (Stavropoulos-Kalinoglou et al. 2008). However, the literature on smoking in aging women is scarce and mainly focuses on the effect of developing early menopause (Hayatbakhsh et al. 2012). A proposed reason for smokers' early menopause is that smoking is detrimental to ovarian function and promotes follicular atresia (Mattison and Thorgeirsson 1978; Ginsberg 1991). Moreover, it has been shown that women who smoke experienced difficulties in conception and infertility; hence, these findings support the observed negative effect of smoking on the womens' reproductive systems (Olsen et al. 1983; Baird and Wilcox 1985). Although it is well known that menopause increases fat mass and decreases MM (North American Association for the Study of Obesity et al. 2000; World Health Organization 2011), smoking may have different effects on body composition parameters (Canoy et al. 2005), depending on gender, age category and menopausal status. Currently, studies regarding the effect of smoking on body composition in midlife women are rare and yield inconsistent result. For example, some of them concluded that smoking decreases FM (Ambikairajah et al. 2019), and another one suggested that smoking is associated with an increase in FM (Portugal et al. 2019). Unclear previous results are also characterized for MM (Kwaśniewska et al. 2012; Graff-Iversen et al. 2019).

Our hypothesis suggests that the significant interaction effect of these two factors – smoking and menopause, exists. Due to the inconsistent data in the literature on the relationship between smoking and body composition variables in middle-aged women, the present study aims to investigate this issue after adjusting for age and physical activity. In addition, to our knowledge, there has not been a single report on their combined effect on body composition, this issue should be investigated. Therefore, in this cross-sectional study, we analyzed the relationships between smoking and body composition in middle-aged women according to their menopausal status, and the interaction effect of smoking and menopause on body composition.

Materials and Methods

The investigated sample consisted of a homogenous sample of 542 middle-aged Slovak women between 39 to 65 years of age (mean age 49.67 ± 6.169 years). This study was based on data collected during two cross-sectional surveys in Slovakia. Participants were recruited from different localities in Slovakia's western, southern, and middle parts by invitation letter. The recruitment involved a non-random procedure based on volunteering and convenience. Collected data was anonymized and analyzed solely for scientific purposes. Data was collected between 2009 and 2015 by the Department of Anthropology at Comenius University in Bratislava and performed in cooperation with general practitioners. The sample included only women who provided written informed consent to participate in the study to adhere to the Declaration of Helsinki principles. Women who could not respond due to severe physical or mental illness and with whom anthropometry and body composition analysis could not be performed were excluded from the study. The women were interviewed using pre-tested, interviewer-administered questionnaires of their reproductive and menstrual history, socio-demographic background, lifestyle, and health status designed by Kaczmarek (2007) and validated in Polish studies (The Menopause-Specific Questionnaire, A. Mickiewicz University Poznań, Poland, Maria Kaczmarek). All socio-demographic and lifestyle variables were measured by self-reporting. Smoking status was categorized as current 'smokers' (smoking once a week to every day) and nonsmokers (never smoking). Physical activity was categorized into two groups, regular and never, including occasional. Women were divided according to their menopausal status into late pre-, peri, and postmenopausal groups. The late premenopausal group included women who had experienced regular menstruation during the last 12 months, which continued at the time of the study. The perimenopausal group included women who reported that their menstrual cycle length had become more irregular in the preceding 12 months or that they had stopped menstruating for between 3 and 12 months. Women were considered postmenopausal if they reported 12 consecutive months of amenorrhea before the examination (Vorobeľová et al. 2019). Due to the low number of perimenopausal women, this group was merged with the premenopausal group. This combined group was analyzed in an association study between smoking status and body composition parameters, in our efforts to compare women in the reproductive period (defined as the late premenopausal and perimenopausal) and in the postreproductive period (defined as postmenopausal).

Anthropometric and body composition analysis

The anthropometric measurements were taken after participants had removed shoes and heavy clothing. Data were taken by trained anthropologists using standard techniques; body height was measured within 0.5 cm accuracy by a Sieber and Hegner anthropometer at head level with the participant standing barefoot with feet together; body weight was measured on a personal balance scale within 0.1 kg accuracy; and BMI was calculated as body weight divided by height squared. The waist and hip circumferences were measured according to the NHLBI Obesity Education Initiative (Audrain-McGovern and Benowitz 2011) and WHO (World Health Organization 2011). WHR was calculated as the circumference of the waist divided by the circumference of the hips. Body composition measurements were carried out in the morning. The body composition was measured using the bioelectric impedance analyzer (BIA 101, Akern S.r.l.) at a signal frequency of 50 kHz, with a constant excitation current at 800 μA and a four-electrode arrangement. Bioimpedance is a complex quantity composed of resistance (R, Ohm) related to the quantity of fluids and reactance (Xc, Ohm) related to the capacitance of the cell membrane. Individual variables of body composition such as phase angle (PhA), fat mass (FM), fat-free mass (FFM), muscle mass (MM), body cell mass (BCM), total body water (TBW), extracellular water (ECW), intracellular water (ICW) were obtained using the software Bodygram program (Version 1.21, Akern S.r.l).

Statistical analysis

IBM SPSS for Windows (Statistical Package for the Social Science, version 20.0, Chicago, IL) was used for all statistical analyses, with statistical significance set at $p \leq 0.05$. Baseline descriptive statistics were performed on the entire sample; a division into two pre- and postmenopausal groups was subsequently performed. A one-sample Kolmogorov-Smirnov test assessed the normality assumption hypothesis for continuous variables. The parametric independent sample t-test, the non-parametric Mann-Whitney U test, and the unequal variances t-test tested the differences in smoking and non-smoking groups across the body composition variables. Furthermore, due to multiple statistical comparisons, to reduce the increased risk of a type I error, the Bonferroni correction (p-value < 0.05/n) was used by multiplying the p-value by the number of comparisons. Two-way ANCOVA analyses were conducted on the dependent variables FM%, FFM%, MM%, BMI, TBW%, ECW%, and ICW%, with age, education level, physical activity, hypertension, and chronic cardiovascular disease as covariates to evaluate the relationship between smoking status and body composition parameters. The variable age required logarithmic transformation because the values were not normally distributed.

Results

The sample encompassed 303 (52.97%) late pre- and perimenopausal women and 269 (47.03%) postmenopausal, out of which 11.71% declared to be regularly physically active, 88.29% not physically active or only occasionally, 30.07% smokers and 69.93% non-smokers. In addition, 78 (13.64%) declared to smoke occasionally and 95 (16.61%) daily, out of these 7 women reported to smoke between 1 to 5 cigarettes per day, 26 between 6 and 10 cigarettes per day, 34 between 11 and 20 cigarettes per day and only 2 smoke more than 20 cigarettes per day. In the pre- and perimenopausal group, 28.71% smoked, and 13.53% were regularly physically active; in the postmenopausal group, 31.60% were smokers, and 9.67% were regularly physically active. As expected, the mean age of the postmenopausal group was significantly higher (54.25 ±4.82) compared to the mean age in the pre- and perimenopausal group (45.62±4.04)

(p <0.001). The BMI of the entire sample corresponded to the WHO category pre-obesity with a mean value of 27.07; moreover, post-menopausal women had a higher BMI (28.25) than pre- and perimenopausal women (26.02). This pattern was also observed in the WHR variables since it correlates to the BMI. Inversely, in the raw bioelectrical impedance data Xc, R, and PhA, higher values were reported in the postmenopausal women. Similar mean values across the two groups were found in the BCM%, with almost no difference, 47.13 in pre- and perimenopausal and 47.67 in postmenopausal. Moreover, postmenopausal women had a higher TBW% and ICW% but lower ECW% than pre- and perimenopausal women. MM% and FFM% were notably lower in postmenopausal women, whereas FM% was higher, aligning with the BMI, and WHR; values. Statistically significant differences among those described above were obtained by utilizing a Student's t-test on the variables: age (p <0.001), Xc (p = 0.048), R (p = 0.020), TBW% (p <0.001), ECW% (p = 0.001), ICW% (p = 0.001), MM% (p <0.001), FFM% (p <0.001) and FM (p <0.001); whereas, due to a non-normal data distribution, a Mann-Whitney U test was performed on the variables: BMI (p <0.001), WHR (p <0.001), and as well as PA, and BCM%, which were not statistically significant. After adjusting the p-value with Bonferroni correction, most of the differences remained significant, as shown in Table 1.

Tab. 1. Baseline characteristics of the participants

	Entire sample (N = 572)		Pre- and perimenopausal women (N = 303)		Postmenopausal (N = 269)		*p*	Adjusted p[a]
	Mean	SD	Mean	SD	Mean	SD		
Age	49.67	6.17	45.62	4.04	54.24	4.82	<0.001*	<0.001*
BMI	27.07	5.61	26.02	5.29	28.25	5.74	<0.001*	<0.001*
WHR	0.83	0.08	0.81	0.08	0.85	0.07	<0.001*	<0.001*
Xc	61.30	10.49	62.12	10.30	60.38	10.65	0.048*	0.714
R	543.53	68.45	549.78	68.00	536.49	68.40	0.020*	0.305
PhA	6.44	0.88	6.45	0.86	6.43	0.91	0.302	1.000
BCM%	47.39	2.88	47.13	1.95	47.67	3.63	0.998	1.000
TBW%	48.45	5.22	49.43	4.93	47.36	5.33	<0.001*	<0.001*
ECW%	44.77	2.92	44.41	2.80	45.19	3.01	0.001*	0.021*
ICW%	55.23	2.93	55.60	2.81	54.81	3.01	0.001*	0.019*
MM%	36.88	4.92	37.59	4.63	26.09	5.12	<0.001*	0.004*
FFM%	62.50	8.34	64.06	8.02	60.75	8.36	<0.001*	<0.001*
FM%	37.48	8.34	35.94	8.02	39.21	8.37	<0.001*	<0.001*

Notes: *marks a statistically significant difference a Bonferroni correction

Abbreviations: BMI: body mass index; WHR: waist-to-hip ratio; Xc: reactance; R: resistance; PhA: phase angle; BCM%: body cell mass percent; TBW%: total body water percent; ECW%: extracellular water percent; ICW%: intracellular water percent; MM%: muscle mass percent; FFM%: fat-free mass percent; FM%: fat mass percent.

Tab. 2. Pre- and perimenopausal smokers and nonsmokers

Body composition variables	Smokers (N= 87)		Nonsmokers (N= 216)		*p*	Adjusted *p*[a]
	Mean	SD	Mean	SD		
BMI	26.66	5.19	25.76	5.31	0.066	0.924
WHR	0.82	0.07	0.80	0.08	0.060	0.840
Xc	63.36	9.89	61.62	10.44	0.184	1.000
R	546.64	59.28	551.04	71.30	0.611	1.000
PhA	6.63	0.98	6.38	0.80	0.045*	0.630
BCM%	47.57	2.08	46.96	1.88	0.014*	0.196
TBW%	48.69	5.06	49.72	4.85	0.098	1.000
ECW%	44.13	2.72	44.52	2.83	0.266	1.000
ICW%	55.87	2.72	55.49	2.84	0.277	1.000
MM%	37.18	4.60	37.75	4.65	0.328	1.000
FFM%	62.87	8.16	64.54	7.93	0.101	1.000
FM%	37.13	8.16	35.46	7.93	0.101	1.000

Notes: *marks a statistically significant difference a Bonferroni correction

Abbreviations: BMI: body mass index; WHR: waist-to-hip ratio; Xc: reactance; R: resistance; PhA: phase angle; BCM%: body cell mass percent; TBW%: total body water percent; ECW%: extracellular water percent; ICW%: intracellular water percent; MM%: muscle mass percent; FFM%: fat-free mass percent; FM%: fat mass percent.

Menopausal status and smoking

The differences between the two groups (smokers and nonsmokers) across the variables under study in pre- and perimenopausal and postmenopausal women are summarized in Table 2. In pre- and perimenopausal women, the analysis of the variables BMI, WHR, and PhA, revealed a statistically significant difference only in PhA values of smokers and non-smokers, U = 8014.50, z = 2.005, p = 0.045, r = 0.15. Further tests were performed on the following variables: Xc, R, BCM%, TBW%, ECW%, ICW%, MM%, FFM%, and FM%. Statistical difference was obtained only for the variable BCM% (p = 0.014). The magnitude of the difference in the means (mean difference = -0.608, 95% CI: -1.093 to -0.124) was minimal (eta squared = 0.019). However, after adjusting the p-values with a Bonferroni correction, no statistical significance was reported in any of the variables. Similarly, the same analyses were performed in the postmenopausal group, as shown in Table 3. On the variables BMI, PhA, and BCM%, statistically significant differences were recorded in BMI (p = 0.001, r = 0.26) values of smokers and nonsmokers. On average, postmenopausal women who smoke had a significantly lower BMI 26.66 versus 28.9. Moreover, the following variables: Xc ($p = 0.001$), R ($p = 0.032$), ECW% ($p < 0.001$), ICW% ($p < 0.001$), MM% ($p < 0.001$), FFM% ($p < 0.001$), and FM% ($p < 0.001$), showed statistically significant differences between smokers and nonsmokers. The magnitude of the difference in the means of the variables was small: Xc (mean difference = -4.473, 95% CI: -7.175 to -1.772; eta squared = 0.038), R (mean difference = -19.153, 95% CI: -36.696 to -1.611; eta squared = 0.017), ECW% (mean difference = 1.389, 95% CI: 0.629 to 2.149; eta squared = 0.046), ICW% (mean difference = -1.389, 95% CI: -2.149 to -0.629; eta squared = 0.046), MM% (mean difference = -2.203, 95% CI: -3.500 to -0.906; eta squared = 0.040), FFM% (mean difference = -4.224, 95% CI: -6.326 to -2.123; eta squared = 0.055), and FM% (mean difference = 4.170, 95% CI: 2.064 to 6.276; eta squared = 0.053). In this case, smokers had higher values of Xc (63.44) compared to nonsmokers (58.96). In accordance with the results obtained in the variable BMI, it was observed that smokers had significantly more MM% and FFM% and lower FM% overall than nonsmokers. ICW% had a greater value in smokers at 55.76 compared to nonsmokers, whose value was 54.37; contrarily, ECW% was higher in non-smokers (45.63) compared to smokers (44.24). For WHR and TBW% a parametric test was used (due to the unequal variances), resulting in a statistically significant difference only in TBW% ($p = 0.001$), with higher scores in smokers at 49.13 than nonsmokers at 46.54. After calculating the adjusted p-value taking into account the following confounding factors: age, education level, physical activity, hypertension, and chronic cardiovascular disease, statistical significance was maintained across most of the variables BMI ($p = 0.009$), Xc ($p = 0.018$), TBW% ($p = 0.001$), ECW% ($p = 0.006$), ICW% ($p = 0.006$), MM% ($p = 0.002$), FFM% ($p = 0.001$) and FM% ($p = 0.001$). The association of smoking and menopausal status with body composition parameters was studied while controlling for age and physical activity (Tab. 4). A significant interaction effect was observed between menopausal status and smoking across all the dependent variables, except for ECW% and ICW%; FM%, $p < 0.001$ with a small effect size (partial eta squared = 0.025) indicating that the influence of menopausal status and smoking on FM% is not uniform across all individuals with an approximately 2.5% of variance; FFM%, $p < 0.001$ with the same effect size (partial eta squared = 0.025) confirming the impact of menopausal status and smoking on FFM%; MM%, $p = 0.002$ similarly with a small effect size (partial eta squared = 0.016) suggests similarly to FM% the presence of non-uniformity in the group and that only 1.6% of the variance in MM% is explained by the interaction effect between menopausal status and smoking; likewise results are found for the variable BMI, $p = 0.003$ (partial eta squared = 0.016) and TBW%, $p < 0.001$, (partial eta squared = 0.025) showing that TBW% is influenced as the previous variables by the interaction between menopausal status and smoking. To summarize, in postmenopausal women the interaction between menopause and smoking leads to significant changes in body compostion parametres such as FM%, FFM%, MM%, BMI and TBW%.

Tab. 3. Postmenopausal smokers and nonsmokers

Body composition variables	Smokers (N = 85)		Nonsmokers N = 184)		*p*	Adjusted *p*[a]	Adjusted p[b]
	Mean	SD	Mean	SD			
BMI	26.66	6.07	28.99	5.45	0.001*	0.014*	0.009*
WHR	0.83	0.08	0.85	0.07	0.065	0.910	0.290
Xc	63.44	11.56	58.96	9.92	0.001*	0.018*	0.018*
R	549.59	75.76	530.43	64.03	0.032*	0.448	0.094
PhA	6.60	1.08	6.35	0.81	0.104	1.000	0.209
BCM%	47.56	2.73	47.73	3.98	0.376	1.000	0.855
TBW%	49.13	6.28	46.54	4.63	0.001*	0.013*	0.001*
ECW%	44.24	3.19	45.63	2.82	<0.001*	0.005*	0.006*
ICW%	55.76	3.19	54.37	2.82	<0.001*	0.005*	0.006*
MM%	37.60	5.78	35.39	4.64	<0.001*	0.013*	0.002*
FFM%	63.64	10.01	59.41	7.11	<0.001*	0.001*	0.001*
FM%	36.36	10.01	40.53	7.14	<0.001*	0.002*	0.001*

Notes: *marks a statistically significant difference a Bonferroni correction; b adjusted for age, education level, physical activity, hypertension, and chronic cardiovascular disease by analysis of covariance

Abbreviations: BMI: body mass index; WHR: waist-to-hip ratio; Xc: reactance; R: resistance; PhA: phase angle; BCM%: body cell mass percent; TBW%: total body water percent; ECW%: extracellular water percent; ICW%: intracellular water percent; MM%: muscle mass percent; FFM%: fat-free mass percent; FM%: fat mass percent.

Tab. 4. An association of smoking and menopausal status on body composition parameters

Dependent variables	Predictors	Observed power	Partial η2	F	*p*
FM%	Smoking	0.371	0.103	2.669	0.103
	Menopausal status	0.087	0.001	0.320	0.572
	Physical activity	0.974	0.026	15.309	<0.001*
	logAge	0.645	0.010	5.454	0.020*
	Menopausal status x smoking	0.966	0.025	14.372	<0.001*
FFM%	Smoking	0.386	0.005	2.798	0.095
	Menopausal status	0.091	0.001	0.351	0.554
	Physical activity	0.975	0.027	15.477	<0.001*
	logAge	0.647	0.010	5.483	0.020*
	Menopausal status x smoking	0.969	0.025	14.691	<0.001*

Dependent variables	Predictors	Observed power	Partial η2	F	*p*
MM%	Smoking	0.461	0.006	3.475	0.063
	Menopausal status	0.110	0.001	0.507	0.477
	Physical activity	0.944	0.022	12.614	<0.001*
	logAge	0.248	0.003	1.637	0.201
	Menopausal status x smoking	0.861	0.016	9.307	0.002*
BMI	Smoking	0.271	0.003	1.823	0.178
	Menopausal status	0.105	0.001	0.472	0.493
	Physical activity	0.955	0.023	13.375	<0.001*
	logAge	0.718	0.011	6.465	0.011*
	Menopausal status x smoking	0.857	0.016	9.189	0.003*
TBW%	Smoking	0.374	0.005	2.692	0.101
	Menopausal status	0.113	0.001	0.533	0.466
	Physical activity	0.973	0.026	15.214	<0.001*
	logAge	0.570	0.008	4.582	0.033
	Menopausal status x smoking	0.964	0.025	14.224	<0.001*
ECW%	Smoking	0.884	0.017	9.989	0.002*
	Menopausal status	0.182	0.002	1.104	0.294
	Physical activity	0.754	0.012	7.034	0.008*
	logAge	0.987	0.030	17.644	<0.001*
	Menopausal status x smoking	0.340	0.004	2.401	0.122
ICW%	Smoking	0.880	0.017	9.868	0.002*
	Menopausal status	0.178	0.002	1.071	0.301
	Physical activity	0.750	0.012	6.957	0.009*
	logAge	0.987	0.030	17.580	<0.001*
	Menopausal status x smoking	0.346	0.004	2.448	0.118

Notes: *marks a statistically significant difference FM%: fat mass percent; FFM%: fat-free mass percent; MM%: muscle mass percent; BMI: body max index; TBW%: total body water percent; ECW%: extracellular water percent; ICW%: intracellular water percent.

Discussion

Menopause is a physiological aging process that occurs in women. Nonetheless, numerous aspects are still unclear and insufficiently studied. The first finding of our research was that postmenopausal women had, as expected, a higher BMI, WHR, and FM% compared to premenopausal women. This finding corresponds to data reported by Juppi et al. (2022), who reported in a short and long-term follow-up research an increased in BMI of between 1% and 3% ($p < 0.001$) as well as a significant increase of total, regional, and subcutaneous fat tissue. The analysis was conducted on a sample of 316 postmenopausal women from two longitudinal cohort studies and a short-term follow-up study on 230 perimenopausal women who were researched leading up to menopause. Furthermore, Greendale et al. (2019) studied a sample of 1,246 pre and postmenopausal women of different ethnicities and observed that during menopause, the average woman's FM rise rate nearly doubled from 1%–1.7% per year, resulting in a 6% overall gain in FM. The cause of this change in body composition is still debated although it tends to be attributed to aging and not menopause (Luptáková et al. 2012, 2013; Danková et al. 2014) but the increase in central adiposity is associated with a possible change in FM distribution after menopause. These changes are most likely to be the result of hormonal shifts during mid-life when women have a higher testosterone-to-estradiol ratio after menopause, which has been linked to increased central adiposity deposition, as reported by Ambikairajah et al. (2019) in a systematic review that analyzed 201 cross-sectional studies, collaborating a sample size of 1,049,919 individuals. In our study, no statistical significance was found across the body composition variables mentioned above in the groups of smokers and nonsmokers in premenopausal women. Similar results were obtained by Portugal et al. (2019), with no significant differences in TBW, ECW-to-ICW ratio, FM, and FFM in both women and men, between the categories never smoker, former smoker, and current smoker. In contrast, postmenopausal women who smoke were found to have a significantly lower BMI value ($p = 0.014$), and lower FM% ($p = 0.002$), whereas MM% ($p = 0.013$) and FFM% ($p = 0.001$) had higher values compared to nonsmokers. In addition, after adjusting for age, education level, physical activity, hypertension, and chronic cardiovascular disease (CVD) in the covariance analysis, the menopause and smoking-associated differences in anthropometric and body composition parameters were consistent. The finding that cigarette smokers are generally leaner compared to non-smokers is consistent with many previous studies (Akbartabartoori et al. 2005; Danková et al. 2014). Lower BMI in smokers was also reported by Kwaśniewska et al. (2012) in a sample of 7,792 Polish women and by Graff-Iversen et al. (2019) in a cross-sectional study conducted in Norway on 22,294 women. More in-depth cross-sectional analyses (Piirtola et al. 2018) on twins compared three groups: current-never, former-current, and former-never smokers, finding that even though current smokers tend to have a lower BMI. Some studies observed a lower amount of FM, especially in visceral areas. Onat et al.´s study (Jandíková et al. 2014) established that smoking Turkish adult women had a lower visceral adipose tissue area than those who never smoked. Therefore, the authors concluded that body FM and visceral fat accumulation are inhibited by cigarette smoking in women. However, the results related to visceral fat among smokers and nonsmokers are often contradictory, as reported in a cross-sectional study of women aged 18–80 years from different ethnicities (Brand et al. 2011). Therein, smoking caused an increase in visceral fat mass conversely and thus represented a metabolic and cardiovascular risk factor. A study by Graff-Iversen et al. (2019) supported this suggestion by showing that waist circumference and WHR was larger for current smokers than in those who never smoked. On the other hand, the same study also observed a negative association between smoking and hip circumference. In the perspective of research concluding that a higher percentage of gluteofemoral fat is linked to lower cardiovascular disease risk, the authors further suggested that smoking could be a modifying cardiovascular disease risk factor through mechanisms that reduce fat storage capacity in the lower body region. Although a large number of studies have reported an association between smoking and lower adiposity, most of these studies did not take into account the effect of menopausal status (Van Geel et al. 2009). Considering our results, we hypothesize that this association concerns postmenopausal rather than late pre- and perimenopausal women. According to the review by Audrain-McGovern et al. (2011), most of the effects of smoking on body weight and fat deposits are likely to be mediated through nicotine. An old animal study on rodents demonstrated that nicotine increases sympathetic nervous system activity and thermogenesis in adipose tissues, thus increasing whole-body metabolism, which might subsequently affect the decrease in adiposity (Yuki et al. 2015). Moreover, nicotine intake is known to result in an increase in fat oxidation and a decrease in fat accumulation (Stachenfeld et al. 1998; Lee and Choi 2019). Androgens hormones might mediate the link between smoking and the greater amount of MM and FFM observed in our study. It has been reported that current smokers have higher circulating levels of testosterone and free testosterone (Stachenfeld 2008). Similarly, Jandikova et al. (2014) found higher levels of androgens in smoking postmenopausal women. Furthermore, limited data indicated there may be a positive association between testosterone with MM and lean body mass in older women (Serra-Prat et al. 2019; Hioka et al. 2021). In addition, it has also been observed that a low-free testosterone level appears to be a significant predictor of loss of appendicular muscle in Japanese women (Park et al. 2021). Therefore, we hypothesize that androgens could also play an important role in smoking – higher MM association in our study sample. However, despite the described above studies and our results, smoking was conversely reported by Lee et al. (2019) to accelerate MM loss in currently smoking middle-aged women, compared to past and never smokers. Our study also concluded that postmenopausal smokers had higher TBW% ($p = 0.013$) and ICW% ($p = 0.005$) but lower ECW% ($p = 0.005$) than nonsmokers. The relationship between hydration and smoking in postmenopausal women, to the best of our knowledge, has not been studied. However, it is known that body fluid distribution is associated with sex hormones, where estrogen increases and progesterone tends to decrease its levels (Stachenfeld et al. 1998, 1999; Stachenfeld 2008). The population-based study of postmenopausal women found that current smokers had higher circulating levels of estradiol compared with non-smokers (Olsen et al. 1983). Endogenous female sex hormones may thus provide one plausible mechanism through which cigarette smoking influences TBW% in postmenopausal women. Furthermore, in a more recent study, Serra-Prat et al. (2019) observed a decline in TBW and ICW in the elderly (both men and women) which was associated with decreased muscle strength and mass. In addition, Hioka et al. (2021) observed in correlation analyses on a sample of < 65-year-old women a significant negative correlation between the total body ECW/ICW ratio and handgrip strength associated with deterioration of muscle quality. Moreover, individuals with sarcopenia had a higher prevalence of abnormal ECW/TBW ratio (Kleppinger et al. 2010).

Limitations and recommendations for future research

The results of our study enrich the literature on the topic. However, this study examined data from a cross-sectional study that can only examine correlations in data; it does not confirm a causal relationship between smoking, menopause, and body composition. In addition, the same individuals were not surveyed over time, and the lifestyle and personal data on smoking, physical activity, and menopause were gathered through self-reporting, which means that there may have been inaccuracies and/or other factors might have influenced the trends observed in our data. Moreover, the research parameters were non-specific; data on the frequency and intensity of physical activity was not gathered, as well as the number of cigarettes smoked per day and whether the nonsmokers have ever smoked in the past. Long-term follow-ups and more detailed data collection can overcome these limitations. Furthermore, due to the missing data on hormone levels in our study sample, our hypothesis about the relationship between smoking, sex hormones, and body composition parameters should be examined in future research. Considering the findings from the literature that the association of smoking with body fat can differ depending on the location of the FM, further studies regarding this relationship in postmenopausal women would be relevant. Another potential limitation of our study is the lack of data on dietary habits, calorie intake and water consumption, which are important predictors of body composition and could be important covariates to include in the study of the relationship between menopause, smoking and anthropometric parameters. Moreover, the methodology used, BIA, since it tends to underestimate FM, is recommended to perform further testing with other methodologies such as DEXA or specificBIVA (Marini et al. 2013) a valid technique for evaluation of FM% and ICW/ECW. We also suggest that cut-off values for FM and MM should be reconsidered in postmenopausal smokers, lower for FM and higher for MM, in future clinical research.

Conclusions

The results obtained in this study can aid healthcare professionals in tailoring recommendations aimed for postmenopausal women regarding lifestyle changes, preventive measures as well as counseling and support for smoke cessation. Such recommendation could be especially important to postmenopausal midlife women who regularly smoke, as these individuals may show lower FM and higher MM that are indicators usually associated with better health outcomes and may mistakenly point to a better health status in these women. Moreover, the findings can provide a basis for evidence-based public health policies and interventions that can raise awareness of the adverse effects on body composition of smoking during menopause. However, due to the limitations of our study, future research is needed to examine the reported in our study associations.

Authors' contribution

Simona Sulis was responsible for the statistical analysis, writing of the manuscript, analysis, and interpretation of data. Petra Švábová participated in data collection, analysis, and interpretation of data. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

This work was supported by the Scientific Grant Agency (Grant VEGA 1/0493/13) and by the Cultural and Educational Grant Agency (KEGA 015UK-4/2015).

Conflicts of Interest

The authors declare no conflict of interest.

Corresponding author

Simona Sulis, Ilkovičova 3278/6, 841 04, Bratislava, Slovakia, +421 2 9014 9473, e-mail: sulis3@uniba.sk

References

Akbartabartoori M, Lean MEJ, Hankey CR. 2005. Relationships between cigarette smoking, body size and body shape. Int J Obes 29:236–243. https://doi.org/10.1038/sj.ijo.0802827

Allen AM, Oncken C, Hatsukami D. 2014. Women and Smoking: The Effect of Gender on the Epidemiology, Health Effects, and Cessation of Smoking. Curr Addict Rep 1:53–60. https://doi.org/10.1007/s40429-013-0003-6

Al-Safi ZA, Polotsky AJ. 2015. Obesity and Menopause. Best Practice & Research Clinical Obstetrics & Gynaecology 29:548–553. https://doi.org/10.1016/j.bpobgyn.2023.102348

Ambikairajah A, Walsh E, Tabatabaei-Jafari H, Cherbuin N. 2019. Fat mass changes during menopause: a metaanalysis. American Journal of Obstetrics and Gynecology 221:393-409.e50. https://doi.org/10.1016/j.ajog.2019.04.023

Aragão FR, Abrantes CG, Gabriel RE, Sousa MF, Castelo-Branco C, Moreira MH. 2014. Effects of a 12-month multi-component exercise program on the body composition of postmenopausal women. Climacteric 17:155–163. https://doi.org/10.3109/13697137.2013.819328

Audrain-McGovern J, Benowitz NL. 2011. Cigarette Smoking, Nicotine, and Body Weight. Clin Pharmacol Ther 90:164–168. https://doi.org/doi:10.1038/clpt.2011.105

Baird DD, Wilcox AJ. 1985. Cigarette smoking associated with delayed conception. JAMA 253:2979–2983. https://doi.org/10.1001/jama.1985.03350440057031

Bendinelli B, Pastore E, Fontana M, Ermini I, Assedi M, Facchini L, Querci A, Caini S, Masala G. 2022. A Priori Dietary Patterns, Physical Activity Level, and Body Composition in Postmenopausal Women: A Cross-Sectional Study. IJERPH 19:6747. https://doi.org/10.3390/ijerph19116747

Brand JS, Van Der Tweel I, Grobbee DE, Emmelot-Vonk MH, Van Der Schouw YT. 2011. Testosterone, sex hormone-binding globulin and the metabolic syndrome: a systematic review and meta-analysis of observational studies. International Journal of Epidemiology 40:189–207. https://doi.org/10.1093/ije/dyq158

Canoy D, Wareham N, Luben R, Welch A, Bingham S, Day N, Khaw K-T. 2005. Cigarette Smoking and Fat Distribution in 21, 828 British Men and Women: A Population-based Study. Obesity Research 13:1466–1475. https://doi.org/10.1038/oby.2005.177

Clair C, Chiolero A, Faeh D, Cornuz J, Marques-Vidal P, Paccaud F, Mooser V, Waeber G, Vollenweider P. 2011. Dose-dependent positive association between cigarette smoking, abdominal obesity and body fat: cross-sectional data from a population-based survey. BMC Public Health 11:23. https://doi.org/10.1186/1471-2458-11-23

Dai X, Gil GF, Reitsma MB, Ahmad NS, Anderson JA, Bisignano C, Carr S, Feldman R, Hay SI, He J, Iannucci V, Lawlor HR, et al. 2022. Health effects associated with smoking: a Burden of Proof study. Nat Med 28:2045–2055. https://doi.org/10.1038/s41591-022-01978-x

Danková Z, Siváková D, Luptáková L, Cvíčelová M, Čerňanová V. 2014. The variability of body composition characteristics in pre- and postmenopausal women from Slovakia. Athropol Rev 77:67–76. https://doi.org/10.2478/anre-2014-0006

Danková Z, Vorobel'ova L, Čerňanová V, Drozdova D, Grendar M, Baldovič M, Cvíčelová M, Sivaková, D. 2017. Genetic and environmental biomarkers associated with triglyceride levels in two groups of Slovak women. Genet Test Mol Biomark, 21(1):46−52. https://doi.org/10.1089/gtmb.2016.0205

Dehghan A, Vasan SK, Fielding BA, Karpe F. 2021. A prospective study of the relationships between change in body composition and cardiovascular risk factors across the menopause. Menopause 28:400–406. https://doi.org/10.1097/GME.0000000000001721

Dmitruk A, Czeczelewski J, Czeczelewska E, Golach J, Parnicka U. 2018. Body composition and fatty tissue distribution in women with various menstrual status. Rocz Panstw Zakl Hig 69:95–101.

Donato GB, Fuchs SC, Oppermann K, Bastos C, Spritzer PM. 2006. Association between menopause status and central adiposity measured at different cutoffs of waist circumference and waist-to-hip ratio: Menopause 13:280–285. https://doi.org/10.1097/01.gme.0000177907.32634.ae

Drozdová D, Danková Z, Čerňanová V, Siváková D. 2016. Body composition of Slovak midlife women with cardiovascular complications. Anthropol Rev 79:169–180. https://doi.org/10.1515/anre-2016-0013

Dubnov G, Brzezinski A, Berry EM. 2003. Weight control and the management of obesity after menopause: the role of physical activity. Maturitas 44:89–101. https://doi.org/10.1016/s0378-5122(02)00328-6

Dupuit M, Maillard F, Pereira B, Marquezi ML, Lancha AH, Boisseau N. 2020. Effect of high intensity interval training on body composition in women before and after menopause: a meta-analysis. Exp Physiol 105:1470–1490. https://doi.org/10.1113/ep088654

Efendi V, Özalevli S, Naz İ, Kılınç O. 2018. The effects of smoking on body composition, pulmonary function, physical activity and health-related quality of life among healthy women. Tuberk Toraks 66:101–108. https://doi.org/10.5578/tt.50724

Falbová D, Beňuš R, Vorobeľová L. 2023. Association between smoking status and body composition parameters in a young adult population. Anthropol Rev 86:77–87. https://doi.org/10.18778/1898-6773.86.2.07

Falbová D, Vorobeľová L, Candráková Čerňanová V, Beňuš R, Siváková D. 2019. ACE Insertion/Deletion polymorphism (rs4646994) affects body composition in middle-aged premenopausal women with essential hypertension. Anthropol Rev 82:349–355. https://doi.org/10.2478/anre-2019-0026

Fenton A. 2021. Weight, shape, and body composition changes at menopause. J Mid-life Health 12:187. https://doi.org/10.4103%2Fjmh.jmh_123_21

Ginsberg J. 1991. What determines the age at the menopause? BMJ 302:1288–1289. https://doi.org/10.1136/bmj.302.6788.1288/

Graff-Iversen S, Hewitt S, Forsén L, Grøtvedt L, Ariansen I. 2019. Associations of tobacco smoking with body mass distribution; a population-based study of 65,875 men and women in midlife. BMC Public Health 19:1439. https://doi.org/10.1186/s12889-019-7807-9

Greendale GA, Lee NP, Arriola ER. 1999. The menopause. The Lancet 353:571–580. https://doi.org/10.1016/s0140-6736(98)05352-5

Greendale GA, Sternfeld B, Huang M, Han W, Karvonen-Gutierrez C, Ruppert K, et al. 2019. Changes in body composition and weight during the menopause transition. JCI Insight 4:e124865. https://doi.org/10.1172/jci.insight.124865

Guthrie JR, Dennerstein L, Dudley EC. 1999. Weight gain and the menopause: a 5-year prospective study. Climacteric 2:205–211. https://doi.org/10.3109/13697139909038063

Harraqui K, Oudghiri DE, Mrabti HN, Hannoun Z, Lee L-H, Assaggaf H, et al. 2023. Association between Physical Activity, Body Composition, and Metabolic Disorders in Middle-Aged Women of Ksar el Kebir (Morocco). IJERPH 20:1739. https://doi.org/10.3390/ijerph20031739

Hayatbakhsh MR, Clavarino A, Williams GM, Sina M, Najman JM. 2012. Cigarette smoking and age of menopause: A large prospective study. Maturitas 72:346–352. https://doi.org/10.1016/j.maturitas.2012.05.004

Hioka A, Akazawa N, Okawa N, Nagahiro S. 2021. Increased total body extracellular-to-intracellular water ratio in community-dwelling elderly women is associated with decreased handgrip strength and gait speed. Nutrition 86:111175. https://doi.org/10.1016/j.nut.2021.111175

Jandíková H, Dušková M, Šimůnková K, Rácz B, Hill M, Pospíšilová H, et al. 2014. How Smoking Cessation Influence Hormonal Levels in Postmenopausal Women? Prague Med Rep 115:60–66. https://doi.org/10.14712/23362936.2014.6

Juppi H, Sipilä S, Fachada V, Hyvärinen M, Cronin N, Aukee P, et al. 2022. Total and regional body adiposity increases during menopause—evidence from a follow-up study. Aging Cell (in press; doi: 10.1111/acel.13621). https://doi.org/10.1111/acel.13621

Kaczmarek M. (2007) The timing of natural menopause in Poland and associated factors. Maturitas 20;57(2):139–53. https://doi.org/10.1016/j.maturitas.2006.12.001

Karvonen-Gutierrez C, Kim C. 2016. Association of Mid-Life Changes in Body Size, Body Composition and Obesity Status with the Menopausal Transition. Healthcare 4:42. https://doi.org/10.3390%2Fhealthcare4030042

Kasteridis P, Yen ST. 2012. Smoking Cessation and Body Weight: Evidence from the Behavioral Risk Factor Surveillance Survey. Health Serv Res 47:1580–1602.

Kim JH, Shim KW, Yoon YS, Lee SY, Kim SS, Oh SW. 2012. Cigarette Smoking Increases Abdominal and Visceral Obesity but Not Overall Fatness: An Observational Study. PLoS ONE 7:e45815. https://doi.org/10.1111%2Fj.1475-6773.2012.01380.x

Kleppinger A, Litt MD, Kenny AM, Oncken CA. 2010. Effects of Smoking Cessation on Body Composition in Postmenopausal Women. Journal of Women's Health 19:1651–1657. https://doi.org/10.1089%2Fjwh.2009.1853

Kodoth V, Scaccia S, Aggarwal B. 2022. Adverse Changes in Body Composition During the Menopausal Transition and Relation to Cardiovascular Risk: A Contemporary Review. Women's Health Reports 3:573–581. https://doi.org/10.1089/whr.2021.0119

Kwaśniewska M, Pikala M, Kaczmarczyk-Chałas K, Piwońska A, Tykarski A, Kozakiewicz K, et al. 2012. Smoking status,

the menopausal transition, and metabolic syndrome in women. Menopause 19:194–201. https://doi.org/10.1097/gme.0b013e3182273035
Kwok S, Canoy D, Soran H, Ashton DW, Lowe GDO, Wood D, et al. 2012. Body fat distribution in relation to smoking and exogenous hormones in British women: Body fat, smoking and hormones in women. Clin Endocrinol 77:828–833. https://doi.org/10.1111/j.1365-2265.2012.04331.x
Lee N, Choi C-J. 2019. Smoking and Diabetes as Predictive Factors of Accelerated Loss of Muscle Mass in Middle-Aged and Older Women: A Six-Year Retrospective Cohort Study. Journal of Women's Health 28:1391–1398. https://doi.org/10.1089/jwh.2018.7527
Lovejoy JC, Champagne CM, De Jonge L, Xie H, Smith SR. 2008. Increased visceral fat and decreased energy expenditure during the menopausal transition. Int J Obes 32:949–958. https://doi.org/10.1038/ijo.2008.25
Luptáková L, Benčová D, Siváková D, Cvíčelová M. 2013. Association of *CILP2* and *ACE* Gene Polymorphisms with Cardiovascular Risk Factors in Slovak Midlife Women. BioMed Research International 2013:1–9. https://doi.org/10.1155%2F2013%2F634207
Luptáková L, Sivaková D, Šrámeková D, Cvíčelová M. 2012. The association of cytochrome P450 1B1 Leu432Val polymorphism with biological markers of health and menopausal symptoms in Slovak midlife women. Menopause 19:216–224. https://doi.org/10.1097/gme.0b013e3182281b54
Maltais ML, Desroches J, Dionne IJ. 2009. Changes in muscle mass and strength after menopause. J Musculoskelet Neuronal Interact 9:186–197.
Marini E, Buffa R, Gobbo LA, Salinas-Escudero G, Stagi S, García-Peña C, Sánchez-García S, Carrillo-Vega MF. 2020. Interpopulation Similarity of Sex and Age-Related Body Composition Variations Among Older Adults. IJERPH 17:6047. https://doi.org/10.3390%2Fijerph17176047
Marini E, Sergi G, Succa V, Saragat B, Sarti S, Coin A, et al. 2013. Efficacy of specific bioelectrical impedance vector analysis (BIVA) for assessing body composition in the elderly. J Nutr Health Aging 17:515–521. https://doi.org/10.1007/s12603-012-0411-7
Mattison DR, Thorgeirsson SS. 1978. Smoking and industrial pollution, and their effects on menopause and ovarian cancer. The Lancet 311:187–188. https://doi.org/10.1016/s0140-6736(78)90617-7
Matvienko OA, Alekel DL, Bhupathiraju SN, Hofmann H, Ritland LM, Reddy MB, et al. 2011. Androidal Fat Dominates in Predicting Cardiometabolic Risk in Postmenopausal Women. Cardiology Research and Practice 2011:1–9. https://doi.org/10.4061%2F2011%2F904878
McVay MA, Copeland AL. 2011. Smoking cessation in peri- and postmenopausal women: A review. Experimental and Clinical Psychopharmacology 19:192–202. https://doi.org/10.1037/a0023119
North American Association for the Study of Obesity, National Heart L and Blood Institute, National Institutes of Health (U.S.), NHLBI Obesity Education Initiative. 2000. The Practical Guide : Identification, Evaluation, and Treatment of Overweight and Obesity in Adults. [Bethesda, Md.]: National Institutes of Health, National Heart, Lung, and Blood Institute, NHLBI Obesity Education Initiative, North American Association for the Study of Obesity. Available at: https://www.ncbi.nlm.nih.gov/books/NBK2003/
Olsen J, Rachootin P, Schiødt AV, Damsbo N. 1983. Tobacco Use, Alcohol Consumption

and Infertility. Int J Epidemiol 12:179–184. https://doi.org/10.1093/ije/12.2.179

Opoku AA, Abushama M, Konje JC. 2023. Obesity and menopause. Best Practice & Research Clinical Obstetrics & Gynaecology 88:102348. https://doi.org/10.1016/j.bpobgyn.2023.102348

Park K-S, Lee G-Y, Seo Y-M, Seo S-H, Yoo J-I. 2021. The relationship between extracellular water-to-body water ratio and sarcopenia according to the newly revised Asian Working Group for Sarcopenia: 2019 Consensus Update. Aging Clin Exp Res 33:2471–2477. https://doi.org/10.1007/s40520-020-01766-y

Piirtola M, Jelenkovic A, Latvala A, Sund R, Honda C, Inui F, et al. 2018. Association of current and former smoking with body mass index: A study of smoking discordant twin pairs from 21 twin cohorts. PLoS ONE 13:e0200140. https://doi.org/10.1371/journal.pone.0200140

Portugal MRC, Brito FB, Curioni CC, Bezerra FF, Faerstein E, Koury JC. 2019. Smoking status affects bioimpedance-derived phase angle in men but not in women: The Pró-Saúde Study, Brazil. Nutrition 61:70–76. https://doi.org/10.1016/j.nut.2018.10.029

Serra-Prat M, Lorenzo I, Palomera E, Ramírez S, Yébenes JC. 2019. Total Body Water and Intracellular Water Relationships with Muscle Strength, Frailty and Functional Performance in an Elderly Population. A Cross-Sectional Study. J Nutr Health Aging 23:96–101. https://doi.org/10.1007/s12603-018-1129-y

Sherman SE, D'Agostino RB, Silbershatz H, Kannel WB. 1999. Comparison of past versus recent physical activity in the prevention of premature death and coronary artery disease. American Heart Journal 138:900–907. https://doi.org/10.1016/s0002-8703(99)70015-3

Sipilä S, Törmäkangas T, Sillanpää E, Aukee P, Kujala UM, Kovanen V, Laakkonen EK. 2020. Muscle and bone mass in middle-aged women: role of menopausal status and physical activity. Journal of Cachexia, Sarcopenia and Muscle 11:698–709. https://doi.org/10.1002/jcsm.12547

Stachenfeld NS. 2008. Sex Hormone Effects on Body Fluid Regulation. Exercise and Sport Sciences Reviews 36:152–159. https://doi.org/10.1097/jes.0b013e31817be928

Stachenfeld NS, Dipietro L, Palter SF, Nadel ER. 1998. Estrogen influences osmotic secretion of AVP and body water balance in postmenopausal women. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 274:R187–R195. https://doi.org/10.1152/ajpregu.1998.274.1.r187

Stachenfeld NS, Silva C, Keefe DL, Kokoszka CA, Nadel ER. 1999. Effects of oral contraceptives on body fluid regulation. Journal of Applied Physiology 87:1016–1025. https://doi.org/10.1152/jappl.1999.87.3.1016

Stavropoulos-Kalinoglou A, Metsios GS, Panoulas VF, Douglas KM, Nevill AM, Jamurtas AZ, et al. 2008. Cigarette smoking associates with body weight and muscle mass of patients with rheumatoid arthritis: a cross-sectional, observational study. Arthritis Res Ther 10:R59. https://doi.org/10.1186/ar2429

Svendsen OL, Hassager C, Christiansen C. 1995. Age- and menopause-associated variations in body composition and fat distribution in healthy women as measured by dual-energy x-ray absorptiometry. Metabolism 44:369–373. https://doi.org/10.1016/0026-0495(95)90168-x

Trikudanathan S, Pedley A, Massaro JM, Hoffmann U, Seely EW, Murabito JM, Fox CS. 2013. Association of Female Reproductive Factors with Body Composition: The Framingham Heart Study. The Journal of Clinical Endocrinology & Metabolism 98:236–244. https://doi.org/10.1210/jc.2012-1785

Van Geel TACM, Geusens PP, Winkens B, Sels J-PJE, Dinant G-J. 2009. Measures of bioavailable serum testosterone and estradiol and their relationships with muscle mass, muscle strength and bone mineral density in postmenopausal women: a cross-sectional study. European Journal of Endocrinology 160:681–687. https://doi.org/10.1530/eje-08-0702

Vorobeľová L, Danková Z, Candráková-Čerňanová V, Falbová D, Cvíčelová M, Beňuš R, Siváková D. 2019. Association of the ESR1 polymorphism with menopause and MLXIPL genetic variant influence serum uric acid levels in Slovak midlife women. Menopause 26(10):1185−1192. https://doi.org/10.1097/gme.0000000000001371

Vorobeľová L, Falbová D, Candráková Čerňanová V. 2022. Contribution of environmental factors and female reproductive history to hypertension and obesity incidence in later life. Annals of Human Biology 49:236–247. https://doi.org/10.1080/03014460.2022.2105398

Vorobeľová L, Falbová D, Siváková D. 2021. Differences in body composition between metabolically healthy and unhealthy midlife women with respect to obesity status. Anthropol Rev 84:59–71. https://doi.org/10.2478/anre-2021-0008

World Health Organization. 2011. Waist circumference and waist-hip ratio : report of a WHO expert consultation, Geneva, 8–11 December 2008. Available at: https://www.who.int/publications/i/item/9789241501491

Yuki A, Ando F, Otsuka R, Shimokata H. 2015. Low free testosterone is associated with loss of appendicular muscle mass in Japanese community-dwelling women: Androgen and muscle mass in women. Geriatrics & Gerontology International 15:326–333. https://doi.org/10.1111/ggi.12278