ORIGINAL ARTICLE

Radiofrequency radiation from mobile phones and the risk of breast cancer: A multicenter case–control study with an additional suspected comparison group

Sedigheh Tahmasebi[1], S M J. Mortazavi[2,3], Masumeh Pourghayoomi[4], Peyman Sheikhzadeh[4], James S Welsh[5,6], Fatemeh Seif[7], Mohamed Reza Bayatiani[7], Samaneh Nematollahi[8], Pooya Zohdparast[9], Farnoosh Khoskhati[10], Zahra Ghahramani[11], Farzaneh Allahveisi[12], Pedram Fadavi[13,14], Ali Jomeh Zadeh[15], Saeed Rajaee Nejad[16], Fatemeh Zaker[2], Manijeh Beigi[13], Sakineh Bagherzadeh[17], Mohsen Khosroabadi[18,19], Mehran Yarahmadi[20], Masoud Haghani[2], Safoora Nikzad[21], Najmeh Bahaeddini[22], Maryam Arshadi[3], Shole Rahimi[23], Jamshid Eslami[23], Amirali Fallah[3], Mojtaba Safdari[24], Fatemeh Makarempour[3], Mina Amirinejad[25], Alireza Mortazavi[24,26], Seyed Ali Reza Mortazavi[24,27]

[1]Breast Cancer Research Center, Shiraz University of Medical Sciences, Shiraz, Iran, [2]Ionizing and Non-Ionizing Radiation Protection Research Center (INIRPRC), Shiraz University of Medical Sciences, Shiraz, Iran, [3]Department of Medical Physics and Engineering, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran, [4]Department of Nuclear Medicine, IKHC, Tehran University of Medical Sciences, Tehran, Iran, [5]Department of Radiation Oncology, Edward Hines Jr VA Hospital, Hines, IL, United States, [6]Department of Radiation Oncology, Loyola University Stritch School of Medicine, Chicago, United States, [7]Department of Radiotherapy and Medical Physics, Faculty of Para Medicine, Arak University of Medical Sciences and Khansari Hospital, Arak, Iran, [8]Noncommunicable Diseases Research Center, Bam University of Medical Sciences, Bam, Iran, [9]Petroleum Department, Institute of Petroleum Engineering, School of Chemical Engineering, College of Engineering, University of Tehran, Iran, [10]Department of Medical Physics, School of Medicine, Shiraz University of Medical Science, Shiraz, Iran, [11]Department of Radiology, School of Medicine, Zanjan University of Medical Sciences, Zanjan, Iran, [12]Department of Radiotherapy and Nuclear Medicine, Faculty of Paramedicine, Kurdistan University of Medical Sciences, Sanandaj, Iran, [13]Department of Radiation Oncology, School of Medicine, Iran University of Medical Sciences, Tehran, Iran, [14]Breast Health and Cancer Research Center, Iran University of Medical Sciences, Tehran, Iran, [15]Department of Medical Physics, School of Medicine, Kerman University of Medical Science, Kerman, Iran, [16]Department of Radiation Oncology, School of Medicine, Kerman University of Medical Science, Kerman, Iran, [17]Department of Medical Physics, School of Medicine, Semnan University of Medical Sciences, Semnan, Iran, [18]Department of Medical Physics, North Khorasan University of Medical Sciences, Bojnurd, Iran, [19]Medical Physics Research Center, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran, [20]Radiotherapy Center of Tohid Hospital, Sanandaj, Iran, [21]Department of Medical Physics, School of Medicine, Isfahan University of Medical Science, Isfahan, Iran, [22]Department of Radiology, School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran, [23]Nursing Department, Nursing and Midwifery School, Shiraz University of Medical Sciences, Shiraz, Iran, [24]School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran,[25]Student Committee, Ionizing and Non-Ionizing Radiation Protection Research Center (INIRPRC), Shiraz University of Medical Sciences, Shiraz, Iran, [26]Caldecot Centre, King's College Hospital NHS Foundation Trust, London, UK, [27]Caldecot Centre, King's College Hospital, London, UK

Background: The rapid global increase in mobile phone use has raised concerns about the potential long-term health effects of radiofrequency electromagnetic fields. While most studies have focused on brain tumors, evidence regarding breast cancer remains limited. The objective of the study is to examine the association between mobile phone use and breast cancer risk among women in Iran. **Materials and Methods:** In this multicenter case–control study, 226 women were recruited from diagnostic, mammography, and radiotherapy centers across Iran and classified as controls (no history of breast cancer, $n = 97$), suspected cases (advised to undergo mammography due to breast-related complaints or physician recommendation, $n = 52$), and confirmed cases (histologically verified invasive breast cancer, $n = 77$). Structured questionnaires collected demographic, reproductive, lifestyle, and environmental data,

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Address for correspondence: Dr. Alireza Mortazavi, Caldecot Centre, King's College Hospital NHS Foundation Trust. Caldecot Centre, King's College Hospital NHS Foundation Trust, London, UK.
E-mail: s.mortazavi@nhs.net; alireza.mortazavi.med@gmail.com
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including mobile phone call duration, screen time, and phone placement. Associations were analyzed using multinomial logistic regression, adjusting sequentially for demographic, reproductive, environmental, and lifestyle variables. **Results:** In fully adjusted models, women reporting more than 60 min of daily mobile phone conversations had higher odds of confirmed breast cancer (odds ratio [OR] = 3.49, 95% confidence interval [CI]: 1.02–11.97) and suspected status (OR = 10.84, 95% CI: 2.29–51.41) compared with those using phones <10 min daily. Longer screen time (>4 h/day), later age at menarche, lower education level, and exposure to environmental pollutants were also associated with increased odds. **Conclusion:** Prolonged mobile phone use was associated with higher odds of breast cancer, but this does not imply causation. Given self-reported exposures and potential residual confounding, findings should be interpreted cautiously. Larger prospective studies with objective exposure assessment are warranted.

Key words: Breast cancer, electromagnetic fields, mobile phones, prolonged phone use, radiofrequency radiation

INTRODUCTION

The rapid and widespread adoption of mobile phones has resulted in nearly universal exposure to radiofrequency electromagnetic fields (RF-EMFs). This trend has raised public and scientific concern about the potential long-term biological effects of such exposure, particularly its possible role in carcinogenesis. While several large cohort and case–control studies have investigated associations between mobile phone use and brain tumors, findings remain inconclusive, and evidence regarding other malignancies, such as breast cancer, is scarce. The breast, as a hormonally sensitive organ often exposed to near-field RF radiation from devices carried close to the body, may be vulnerable to such effects. To address this gap, we conducted a multicenter case–control study with an additional suspected comparison group – women advised to undergo mammography due to breast-related complaints – to explore whether patterns of mobile phone use are associated with an increased risk of breast cancer or early clinical suspicion thereof. RF-EMFs are classified as nonionizing radiation, which does not have sufficient energy to directly damage DNA, yet some studies suggest possible carcinogenic effects, especially with prolonged exposure.[1-3]

Current evidence from major cohort studies does not support a clear link between mobile phone use and an increased risk of overall cancer or brain tumors. Positron emission tomography imaging studies have shown altered glucose metabolism in brain exposure.[4] Large-scale cohort studies such as the Danish cohort study[5] and the UK Million Women Study[6] have not demonstrated a significant association between mobile phone use and overall cancer risk, including brain tumors. Cohort study of mobile phone users (COSMOS), a multinational prospective cohort study of mobile phone use and health, included more than 250,000 participants; a large proportion were long-term users. COSMOS found no evidence of increased risk of glioma, meningioma, or acoustic neuroma.[7]

However, case–control studies have yielded mixed findings. The INTERPHONE study, a multinational case–control investigation involving 2708 glioma and 2409 meningioma cases across 13 countries, found no overall increased risk of brain tumors associated with regular mobile phone use. However, it identified a nuanced pattern in the heaviest users.[8,9] The study concluded that biases prevent causal conclusions for the observed glioma risk in heavy users, emphasizing the need for further research on long-term use.

Conversely, Hardell and Carlberg reported increased risks of glioma and acoustic neuroma with long-term use, though results have been criticized.[10]

Animal studies like those by the National Toxicology Program (NTP) and Ramazzini Institute reported increased incidence of rare tumors in rats exposed to RF-EMFs.[11-13] *In vitro* studies have shown increased oxidative stress and DNA damage following RF-EMF exposure, though findings are inconsistent.[3,14] In 2011, the International Agency for Research on Cancer (IARC) classified RF-EMFs as "possibly carcinogenic to humans" (Group 2B).[2,14,15] World Health Organization, Food and Drug Administration, and others have stated that current evidence does not confirm a causal link but supports continued investigation.[3,16]

A UK Biobank study found that weekly mobile phone users had a 19% increased risk of prostate cancer. Risk increased further among long-term users.[17] Swedish studies by Hardell *et al*. indicated a possible synergistic effect between RF-EMFs and genetic predisposition.[18] The NTP study found proliferative lesions in male rat prostates exposed to RF radiation.[13] Proposed mechanisms include local thermal effects, oxidative stress, and hormonal disruption involving testosterone.[3,18,19] Current evidence does not definitively establish RF-EMFs from mobile phones as a carcinogen.[20] However, associations with specific cancers, especially gliomas, acoustic neuromas, and prostate cancer, warrant further study. Precautionary measures like hands-free use may be advisable for long-term users.

Although current evidence does not conclusively establish a causal link between RF-EMF exposure and breast cancer, emerging findings from laboratory and epidemiological studies indicate potential biological

effects that merit closer examination. In particular, prolonged or close-proximity mobile phone use may contribute to oxidative stress, hormonal dysregulation, or altered cellular signaling pathways relevant to breast carcinogenesis. However, few studies have examined this relationship directly in women, and even fewer have explored potential gradients of risk among those with early clinical suspicion of disease.

To address this knowledge gap, we conducted a multicenter case–control study with an additional suspected comparison group across diagnostic and radiotherapy centers in Iran. By comparing women with confirmed breast cancer, women advised to undergo mammography due to breast-related symptoms, and women without breast abnormalities, we aimed to evaluate the association between mobile phone use and breast cancer risk. Using multinomial logistic regression, we further sought to identify potential dose–response relationships and to determine whether lifestyle, reproductive, and environmental factors modify this association.

MATERIALS AND METHODS

Ethical approval

Approval was obtained from Shiraz University of Medical Sciences and the Ministry of Health and Medical Education (IR.SUMS.REC.1404.025). Written informed consent was secured, with confidentiality maintained via coded data and secure storage.

Study design and setting

This was a multicenter case–control study conducted between January and April 2025, with an additional group of women who were advised to undergo mammography included for exploratory comparison. The analysis was performed using multinomial logistic regression, treating the study as an extension of a traditional case–control design.

Participants

Participants were classified into three groups:

1. Confirmed cases: Women with histologically verified invasive breast cancer diagnosed during the study period. Diagnosis was based on biopsy and pathology reports, with disease stage and tumor characteristics recorded where available
2. Suspected cases: Women who were advised to undergo mammography due to breast-related complaints or physician recommendation, but who had not been diagnosed with breast cancer at the time of recruitment
3. Controls: Women with no history of breast cancer who attended the same centers for routine health screening or noncancer diagnostic services.

Controls were frequency-matched to confirmed cases by age (±5 years) and menopausal status. Exclusion criteria included withdrawal of consent, incomplete questionnaires, or inconsistent responses.

Sample size

A total of 226 women were included in the final analysis: 77 confirmed breast cancer cases, 52 suspected cases, and 97 controls. Although conventional case–control designs often include a larger number of controls, the limited number of eligible volunteers from noncancer diagnostic centers resulted in an unequal ratio. Logistic regression modeling accounted for this imbalance without compromising analytical validity.

Data collection

Trained interviewers administered a structured questionnaire that covered the following domains:

- Demographic variables: Age, education, marital status, and income level
- Reproductive history: Age at menarche, parity, breastfeeding history, and hormone therapy use
- Lifestyle and environmental factors: Diet, physical activity, exposure to environmental pollutants, and sleep patterns
- Mobile phone exposure: Daily call duration, screen time, and phone placement (ear, hands-free, or close to chest).

All exposure variables were self-reported. The potential for recall bias and residual confounding was acknowledged.

Exposure definitions

- Call duration: Categorized as <10 min, 11–30 min, 31–60 min, and >60 min per day
- Screen time: Categorized as < 2 h, 2–4 h, 4–6 h, and >6 h per day
- Phone placement: Classified as ear use, hands-free, or close to the chest.

Statistical analysis

Descriptive statistics were computed for all variables. Group differences were assessed using χ^2 tests for categorical variables and ANOVA for continuous variables. Associations between exposure variables and group status were examined using multinomial logistic regression, with controls as the reference category.

Two multivariable models were constructed:

- Model 1: Adjusted for age, weight (kg), education, and reproductive factors (e.g. age at menarche and parity)
- Model 2: Model 1 plus environmental and lifestyle variables, including pollutant exposure, sleep patterns, mobile phone use, and screen time.

Odds ratios (ORs) and 95% confidence intervals (CIs) were reported. Statistical significance was defined as $P < 0.05$. Analyses were conducted using SPSS version 26 (IBM Corp., Armonk, NY, USA).

Study centers

Participants were recruited from a network of hospitals and diagnostic centers across Iran, including IKHC Tehran University of Medical Sciences (Tehran), Arak University of Medical Sciences and Khansari Hospital (Arak), Bam University of Medical Sciences (Bam), Shiraz University of Medical Sciences (Shiraz), Zanjan University of Medical Sciences (Zanjan), Kurdistan University of Medical Sciences and Tohid Hospital (Sanandaj), Iran University of Medical Sciences and Breast Health and Cancer Research Centre (Tehran), Kerman University of Medical Sciences (Kerman), Isfahan University of Medical Sciences (Isfahan), North Khorasan University of Medical Sciences (Bojnurd), and Mashhad University of Medical Sciences (Mashhad).

RESULTS

Descriptive statistics and univariate analysis

The mean age of participants was slightly higher in the case group (48.52 ± 10.76 years) and the suspected group (49.61 ± 9.81 years) compared to the control group (45.88 ± 10.98 years), though this difference was not statistically significant ($P = 0.107$). The age of menarche was significantly later among cases (13.39 ± 1.33 years) compared to controls (12.82 ± 1.31 years) ($P = 0.026$). Duration of breastfeeding was significantly shorter among suspected cases (20.64 ± 7.51 months) compared to controls (35.13 ± 30.24 months) and cases (38.87 ± 29.41 months) ($P < 0.001$).

Weight was significantly higher in cases (71.45 ± 11.20 kg) and suspected cases (72.75 ± 9.28 kg) compared to controls (67.74 ± 13.45 kg) ($P = 0.022$), while height differences were not statistically significant ($P = 0.438$). No significant differences were observed in the age at first pregnancy among the groups ($P = 0.176$).

Regarding qualitative variables, education level showed significant differences between groups ($P < 0.001$), with a higher proportion of high school education among cases. Marital status was also significantly different ($P < 0.001$), with a higher proportion of married individuals among cases and suspected cases.

Several lifestyle factors were significantly different across groups, including number of pregnancies ($P < 0.001$), fruit and vegetable consumption ($P < 0.001$), income level ($P = 0.017$), hormone therapy use ($P = 0.015$), surgery or biopsy history ($P = 0.007$), exposure to pollutants ($P = 0.036$), time spent outside ($P < 0.001$), conversation duration ($P = 0.004$), screen time ($P = 0.003$), difficulty falling asleep ($P = 0.003$), and waking up early ($P < 0.001$).

Other variables such as drug use, menopausal status, fat intake, sugar consumption, processed food consumption, radiation therapy, alcohol use, and physical activity did not show statistically significant differences among the groups.

Multivariate analysis

For each predictor in the multinomial models, we report case versus control and suspected versus control ORs with P values, plus an overall (type III/Wald) P value for the variable across outcome categories.

Model 1

In Model 1, which included selected key variables, several associations were identified:

- Education level was strongly associated with case status; individuals with only a high school education had significantly higher odds of being a case compared to those with associate degrees or higher (OR = 9.430, 95% CI: 2.957–30.074, $P < 0.001$)
- Surgery or biopsy history was significantly associated with increased odds of being a case (OR = 10.638, 95% CI: 3.105–37.04, $P < 0.001$).

Other variables, including age, weight, marital status, and family history, were not statistically significant in this model.

Model 2

Model 2, which included a broader set of variables, confirmed and expanded upon several findings:

- Education level remained significantly associated with case status (high school OR = 5.115, 95% CI: 1.458–17.945, $P = 0.011$)
- Age of menarche was a significant predictor of case status (OR = 1.386, 95% CI: 1.015–1.893, $P = 0.040$)
- Exposure to pollutants was strongly associated with case status (OR = 7.299, 95% CI: 1.901–27.777, $P = 0.004$)
- Mobile phone conversation duration was significant, with spending more than 60 min on phone conversations associated with both cases (OR = 3.494, 95% CI: 1.020–11.97, $P = 0.046$) and suspected status (OR = 10.838, 95% CI: 2.285–51.41, $P = 0.003$)
- Waking up early showed influence on the response variable overall ($P = 0.013$), though individual category comparisons did not reach statistical significance.

Variables such as marital status, family history, number of pregnancies, weight, time spent outside, and room light before sleep were not significantly associated in this model.

Table 1: Quantitative variables by diagnostic group with overall group comparison (ANOVA)

Variables	Control	Case	Suspected	*P*
Age				
Mean±SD	45.88±10.98	48.52±10.76	49.61±9.81	0.107
Minimum–maximum	26–75	19–76	16–75	
Age of menarche				
Mean±SD	12.82±1.31	13.39±1.33	13.15±1.60	0.026*
Minimum–maximum	9–16	10–16	9–16	
Duration of breastfeeding				
Mean±SD	35.13±30.24	38.87±29.41	20.64±7.51	<0.001*
Minimum–maximum	0–120	0–145	0–36	
Age at first pregnancy				
Mean±SD	22.82±5.21	22.83±6.62	24.86±5.94	0.176
Minimum–maximum	15–36	14–48	13–38	
Weight (kg)				
Mean±SD	67.74±13.45	71.45±11.20	72.75±9.28	0.022*
Minimum–maximum	48–160	43–112	55–102	
Height (cm)				
Mean±SD	159.62±12.06	161.52±12.59	161.60±5.37	0.438
Minimum–maximum	70–174	60–182	150–173	

*Statistically significant. SD=Standard deviation

Table 1 presents the descriptive statistics for quantitative variables across the three study groups (controls, suspected, and confirmed cases). It shows that cases and suspected participants tended to have slightly higher mean age and weight and a later age at menarche compared with controls.

Table 2 summarizes categorical variables, including demographic, reproductive, lifestyle, and environmental factors, together with univariate comparisons. Significant between-group differences were observed in education level, marital status, number of pregnancies, income, and several exposure-related variables such as conversation duration, screen time, and sleep patterns.

Table 3 reports the results of the multinomial logistic regression (Model 1) adjusted for demographic and reproductive covariates. Lower education level and a history of breast surgery or biopsy were significantly associated with higher odds of confirmed breast cancer.

Table 4 shows the extended regression model (Model 2), which further adjusted for environmental and lifestyle exposures. In this fully adjusted model, prolonged daily mobile phone conversations (>60 min), longer screen time (>4 h/day), later age at menarche, and exposure to environmental pollutants remained significantly associated with increased odds of both suspected and confirmed breast cancer relative to controls.

DISCUSSION

Although designed as a case–control study, we included a third, intermediate group ("suspected") representing women advised to undergo mammography but not diagnosed with cancer, to explore exposure gradients across the diagnostic spectrum. Our study provides new insights into the possible role of lifestyle and environmental factors – particularly mobile phone use, screen time, and light-at-night exposure – in the etiology of breast cancer. The most consistent and robust finding was the significant association between prolonged daily mobile phone conversations and breast cancer risk. Women who used mobile phones for more than 60 min per day had a 3.5-fold higher risk of confirmed breast cancer and over a tenfold increased risk of being categorized as a suspected case, compared with those reporting <10 min of daily use. This dose-dependent relationship strengthens the biological plausibility of a link between long-term RF-EMF exposure and breast carcinogenesis. Similar case studies have reported multifocal breast cancers in young women who habitually kept mobile phones close to the chest.[21,22] Although large-scale pooled analyses have not demonstrated consistent associations,[23,24] our findings echo concerns raised in reviews suggesting that certain exposure patterns – such as direct skin contact or long-duration daily use – could confer higher risk.[25] Experimental work further supports biological plausibility, with evidence for oxidative stress and proliferative signaling in breast cancer cell lines exposed to RF-EMFs.[26,27] Notably, these observations are aligned with our recent retrospective matched case–control study linking digital screen time with increased breast cancer risk[28] and with our earlier work developing machine-learning models to predict breast cancer risk in women exposed to blue light from digital screens,[29] both of which underscore the potential hazard profile of prolonged, technology-related exposures.

Table 2: Categorical variables by diagnostic group with overall group comparison (χ^2)

Variable		Control	Case	Suspected	*P*
Education level	High school	17 (22.1%)	44 (45.8%)	12 (24%)	<0.001*
	Diploma	20 (26%)	33 (34.4%)	15 (30%)	
	Associate and Higher than Associate	40 (51.9%)	19 (19.8%)	23 (46%)	
Marital status	Single	25 (32.5%)	11 (11.3%)	5 (9.6%)	<0.001*
	Married	52 (67.5%)	86 (88.7%)	47 (90.4%)	
Family History	Not have	65 (84.4%)	67 (69.1%)	35 (67.3%)	0.028*
	Have	12 (15.6%)	30 (30.9%)	17 (32.7%)	
Menopausal Status	Yes	32 (41.6%)	51 (53.7%)	25 (53.2%)	0.238
	No	45 (58.4%)	44 (46.3%)	22 (46.8%)	
Number of Pregnancies	None	26 (33.8%)	12 (12.4%)	3 (6%)	<0.001*
	One time	8 (10.4%)	16 (16.5%)	10 (20%)	
	2-3 times	33 (42.9%)	48 (49.5%)	32 (64%)	
	>3 times	10 (13%)	21 (21.6%)	5 (10%)	
Drug Use	Yes	7 (9.1%)	9 (9.3%)	1 (1.9%)	0.140
	No	70 (90.9%)	88 (90.7%)	51 (98.1%)	
Fruit and vegetable consumption	Low	21 (27.3%)	8 (8.2%)	2 (3.8%)	<0.001*
	Medium	33 (42.9%)	46 (47.4%)	20 (38.5%)	
	High	23 (29.9%)	43 (44.3%)	30 (57.7%)	
Fat Use	Low	39 (50.6%)	42 (43.3%)	26 (50%)	0.873
	Medium	33 (42.9%)	48 (49.5%)	22 (42.3%)	
	High	5 (6.5%)	7 (7.2%)	4 (7.7%)	
Income	<10 million	32 (41.6%)	31 (32%)	29 (63%)	0.017*
	10-15 million	27 (35.1%)	33 (34%)	11 (23.9%)	
	16-30 million	11 (14.3%)	24 (24.7%)	5 (10.9%)	
	>30 million	7 (9.1%)	9 (9.3%)	1 (2.2%)	
Hormone Therapy	Yes	0 (0%)	4 (4.1%)	6 (11.5%)	0.015*
	No	77 (100%)	93 (95.9%)	46 (88.5%)	
Radiation Therapy	Yes	3 (6.4%)	7 (7.4%)	6 (11.5%)	0.612
	No	44 (93.6%)	87 (92.6%)	46 (88.5%)	
Surgery or Biopsy	Yes	5 (6.5%)	32 (33%)	10 (19.2%)	0.007*
	No	72 (93.5%)	65 (67%)	42 (80.8%)	
Exposure to pollutants	Yes	6 (7.8%)	21 (21.6%)	8 (15.4%)	0.036*
	No	71 (92.2%)	76 (78.4%)	44 (84.6%)	
Time Spent Outside	< 1 hour	46 (59.7%)	49 (51%)	27 (51.9%)	<0.001*
	1-2 hours	18 (23.4%)	31 (32.3%)	17 (32.7%)	
	>2 hours	13 (16.9%)	16 (16.7%)	8 (15.4%)	
Sugar consumption	Low	53 (68.8%)	74 (78.7%)	42 (80.8%)	0.271
	Medium	21 (27.3%)	16 (17%)	7 (13.5%)	
	High	3 (3.9%)	4 (4.3%)	3 (5.8%)	
Processed food consumption	Low	72 (93.5%)	89 (95.7%)	49 (94.2%)	0.469
	Medium	5 (6.5%)	4 (4.3%)	2 (3.8%)	
	High	0	0	1 (1.9%)	
Conversation duration	1-10 min	38 (49.4%)	22 (23.4%)	8 (15.7%)	0.004*
	11-30 min	15 (19.5%)	25 (26.6%)	12 (23.5%)	
	min	12 (15.6%)	21 (22.3%)	16 (31.4%)	
	>60 min	12 (15.6%)	26 (27.7%)	15 (29.4%)	
Phone Placement	On ears	71 (94.7%)	90 (96.8%)	47 (94%)	0.674
	Hands-free	4 (5.3%)	3 (3.2%)	3 (6%)	
Screen Time	0-2 hours	18 (23.4%)	39 (41.5%)	23 (45.1%)	0.003*
	2-4 hours	26 (33.8%)	33 (35.1%)	15 (29.4%)	
	4-6 hours	14 (18.2%)	14 (14.9%)	11 (21.6%)	
	>6 hours	19 (24.7%)	8 (8.5%)	2 (3.9%)	
Difficulty falling asleep	Never, rarely	37 (50%)	48 (51.1%)	20 (38.5%)	0.003*
	Sometimes, often	19 (25.7%)	40 (42.6%)	24 (46.2%)	

Contd...

Table 2: Contd...

Variable		Control	Case	Suspected	*P*
	Always	18 (24.3%)	6 (6.4%)	8 (15.4%)	
Waking up early	Never, rarely	14 (18.2%)	26 (26.8%)	3 (5.8%)	<0.001*
	Sometimes, often	25 (32.5%)	51 (52.6%)	28 (53.8%)	
	Always	38 (49.4%)	20 (20.6%)	21 (40.4%)	
Room Light before Sleep	Semi-dark	27 (36.5%)	42 (45.2%)	14 (28%)	0.118
	Completely dark	47 (63.5%)	51 (54.8%)	36 (72%)	
Alcohol Use	Yes	3 (3.9%)	4 (4.3%)	2 (3.8%)	0.993
	No	74 (96.1%)	90 (95.7%)	50 (96.2%)	
Physical activity	Never	26 (35.1%)	32 (34%)	18 (34.6%)	0.382
	Rarely	27 (36.5%)	29 (30.9%)	11 (21.2%)	
	Little	13 (17.6%)	19 (20.2%)	10 (19.2%)	
	A lot	8 (10.8%)	14 (14.9%)	13 (25%)	

*Statistically significant

Table 3: Multinomial logistic regression – Model 1 (demographic and reproductive factors); Reference=Controls

Variables	Groups				Overall *P* (type III/Wald)
	Case		Suspected		
	OR (CI)	*P*	OR (CI)	*P*	
Age	1.021 (0.975–1.069)	0.375	1.033 (0.981–1.088)	0.214	0.436
Age of menarche	1.302 (0.984–1.724)	0.065	1.216 (0.891–1.661)	0.218	0.162
Weight	1.002 (0.966–1.038)	0.930	0.996 (0.955–1.039)	0.843	0.950
Marital status					
Married	1.828 (0.380–8.772)	0.451	1.821 (0.213–15.625)	0.584	0.718
Single	Reference				
Family history					
Yes	1.402 (0.563–3.484)	0.468	1.890 (0.713–5)	0.2	0.438
No	Reference				
Education level					
High school	9.430 (2.957–30.074)	<0.001*	0.913 (0.269–3.094)	0.884	<0.001*
Diploma	4.984 (1.845–13.460)	0.002*	1.155 (0.409–3.262)	0.786	
Associate and higher than associate	Reference				
Number of pregnancies					
None	1.216 (0.133–11.113)	0.863	0.937 (0.059–14.980)	0.963	0.363
One time	3.051 (0.600–15.504)	0.179	5.908 (0.945–36.953)	0.058	
2–3 times	1.611 (0.483–5.381)	0.438	3.349 (0.800–14.023)	0.098	
>3 times	Reference				
Drug use					
Yes	1.282 (0.376–4.367)	0.692	0.501 (0.050–5)	0.556	0.654
No	Reference				
Fruit and vegetable use					
High	7.531 (2.173–26.104)	0.001*	10.743 (1.924–59.98)	0.007*	0.003*
Medium	5.153 (1.597–16.625)	0.006*	5.414 (0.968–30.27)	0.054	
Low	Reference				
Surgery or biopsy					
Yes	10.638 (3.105–37.04)	<0.001*	2.88 (0.704–11.76)	0.141	<0.001*
No	Reference				

**P*<0.05. Overall *P*=Type III/Wald test for the variable across outcome categories; Outcome reference group=Controls; Categorical predictor references: Conversation duration=1–10 min; Screen time=>6 h; Waking up early=Always; Room light=Completely dark. CI=Confidence interval; OR=Odds ratio

Another important finding of this study is the relationship between screen time and breast cancer risk. For suspected breast cancer, screen-time categories of 0–2 hours and 4–6 hours (vs >6 hours) showed significantly higher odds, while 2–4 hours was not statistically significant. Excessive evening screen exposure is a proxy for artificial light-at-night (ALAN), which has been linked to circadian rhythm disruption, suppression of nocturnal melatonin secretion, and estrogen dysregulation.[30] Our results parallel epidemiological evidence showing that women exposed to high levels of ALAN have increased breast cancer incidence.[31,32] Importantly, circadian disruption associated with night

Table 4: Multinomial logistic regression – Model 2 (Model 1 + environmental and lifestyle factors); Reference=Controls

Variables	Groups				Overall *P* (type III/Wald)
	Case		Suspected		
	OR (CI)	*P*	OR (CI)	*P*	
Age	1.011 (0.963–1.063)	0.654	1.040 (0.980–1.103)	0.192	0.417
Age of menarche	1.386 (1.015–1.893)	0.040*	1.346 (0.935–1.938)	0.110	0.093
Weight	1.016 (0.978–1.056)	0.413	1.001 (0.956–1.048)	0.967	0.648
Marital status					
Married	2.024 (0.268–15.38)	0.493	7.874 (0.275–25)	0.228	0.438
Single	Reference				
Family history					
Yes	2.183 (0.808–5.882)	0.124	2.132 (0.687–6.622)	0.190	0.251
No	Reference				
Education level					
High school	5.115 (1.458–17.945)	0.011*	0.423 (0.102–1.760)	0.237	0.001*
Diploma	3.235 (1.142–9.159)	0.027*	0.697 (0.212–2.286)	0.551	
Associate and higher than associate	Reference				
Number of pregnancies					
None	1.551 (0.109–22.133)	0.746	2.118 (0.054–83.34)	0.689	0.752
One time	3.421 (0.573–20.417)	0.177	3.367 (0.391–28.99)	0.269	
2–3 times	1.616 (0.417–6.263)	0.487	2.904 (0.530–15.905)	0.219	
>3 times	Reference				
Exposure to pollutants					
Yes	7.299 (1.901–27.777)	0.004*	3.745 (0.768–18.18)	0.102	0.007*
No	Reference				
Time spent outside (h)					
<1	0.740 (0.247–2.221)	0.592	1.442 (0.378–5.498)	0.592	0.736
1–2	1.243 (0.367–4.203)	0.727	1.918 (0.446–8.244)	0.382	
>2	Reference				
Conversation duration (min)					
>60	3.494 (1.020–11.97)	0.046*	10.838 (2.285–51.41)	0.003*	0.037*
31–60	2.323 (0.704–7.665)	0.166	6.060 (1.369–26.821)	0.018*	
11–30	2.177 (0.727–6.525)	0.165	2.290 (0.571–9.181)	0.242	
1–10	Reference				
Screen time (h)					
0–2	4.099 (0.916–18.34)	0.065	9.37 (1.315–66.75)	0.026*	0.182
2–4	2.097 (0.481–9.151)	0.324	3.944 (0.583–26.66)	0.159	
4–6	2.285 (0.459–11.37)	0.313	8.583 (1.086–67.85)	0.042*	
>6	Reference				
Difficulty falling asleep					
Never (rarely)	2.283 (0.578–9.006)	0.239	0.860 (0.201–3.674)	0.839	0.228
Sometimes (often)	4.037 (0.984–16.561)	0.053	0.927 (0.216–3.971)	0.918	
Always	Reference				
Waking up early					
Never (rarely)	3.358 (0.975–11.564)	0.055	0.119 (0.009–1.624)	0.110	0.013*
Sometimes (often)	2.168 (0.832–5.650)	0.113	1.103 (0.348–3.494)	0.868	
Always	Reference				
Room light before sleep					
Semidark	1.301 (0.549–3.084)	0.549	0.392 (0.137–1.121)	0.081	0.046*
Completely dark	Reference				

*$P<0.05$. Overall P=Type III/Wald test for the variable across outcome categories; Outcome reference group=Controls; Categorical predictor references: Conversation duration=1–10 min; Screen time=>6 h; Waking up early=Always; Room light=Completely dark. CI=Confidence interval; OR=Odds ratio

shift work has been classified by the IARC as "probably carcinogenic to humans."[33] This aligns with our observation that women with sleep disruption (difficulty initiating sleep and early waking) were overrepresented in the breast cancer and suspected groups, consistent with studies linking circadian dysregulation to elevated risk.[34-36] These patterns are consistent with our comprehensive review on blue light and digital screens, which synthesized evidence on circadian,

visual, and cognitive pathways relevant to cancer biology.[37] In addition, our precautionary commentary highlighted that women with hereditary breast cancer predispositions should avoid smartphone, tablet, and laptop use at night to minimize circadian and hormonal disruption.[38]

The role of light in the sleep environment also emerged as an additional factor. While not as strong as mobile phone use and screen time, our models indicated that women sleeping in semidark rooms had higher odds of being in the suspected breast cancer group compared to those in completely dark rooms. This is consistent with studies reporting that bedroom light exposure during sleep may increase breast cancer risk through melatonin suppression and impaired DNA repair.[39,40] Moreover, animal experiments confirm that dim light at night accelerates mammary tumor growth,[41] supporting a mechanistic pathway.

Beyond mobile phone and light-related exposures, our findings confirm the influence of several established risk modifiers, including later age at menarche, higher weight, lower education, and environmental pollutant exposure. Interestingly, a history of breast surgery or biopsy was also a strong predictor, though this may partially reflect reverse causation, with women undergoing more frequent medical evaluation due to prior pathology.

Taken together, our results highlight the complex interplay between RF-EMF exposure, behavioral risk factors such as evening screen use, and circadian disruption in breast cancer risk. While causality cannot be definitively established due to the case–control design and reliance on self-reported exposures, the consistency of associations across multiple variables and their concordance with mechanistic and experimental evidence supports the need for precautionary measures. Public health recommendations could include minimizing prolonged direct chest exposure to mobile phones, reducing evening screen time, and ensuring a dark sleep environment.

Future studies should prioritize prospective cohort designs with objective exposure assessment, such as wearable RF dosimeters and light sensors, alongside biological markers of circadian disruption and oxidative stress. Such approaches will help clarify causal pathways and quantify attributable risk at the population level.

CONCLUSION

Prolonged mobile phone use was associated with increased odds of both suspected and confirmed breast cancer in this multinomial analysis. However, this association does not establish a causal relationship, as exposures were self-reported and potential residual confounding cannot be excluded. These findings should therefore be interpreted with caution, and larger prospective studies with objective exposure measurements are needed to clarify whether this relationship reflects causation or merely correlation.

Authors' Contributions

Sedigheh Tahmasebi, S. M. J. Mortazavi, Masumeh Pourghayoomi, Peyman Sheikhzadeh, James S. Welsh, and Fatemeh Seif contributed equally to this work and are all recognized as co–first authors. Sedigheh Tahmasebi, Alireza Mortazavi, S. M. J. Mortazavi, and James S. Welsh conceptualized and supervised the study and contributed to study design, data interpretation, and manuscript revision. Samaneh Nematollahi, Alireza Mortazavi, and Pooya Zohdparast contributed to statistical analysis and data interpretation. All other authors participated in data collection, data validation, and manuscript drafting. All six co–first authors reviewed and approved the final manuscript and agree to be accountable for all aspects of the work.

Ethics approval and consent to participate

This study was conducted in accordance with the ethical standards of the Declaration of Helsinki. Approval was obtained from Shiraz University of Medical Sciences and the Ministry of Health and Medical Education (IR.SUMS.REC.1404.025). Written informed consent was secured, with confidentiality maintained via coded data and secure storage.

Consent for publication

All participants provided informed consent for the anonymous publication of the study results. No identifiable personal data are presented in this manuscript.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Conflicts of interest

There are no conflicts of interest.

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