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Effects of cell phone use on semen parameters: Results from the MARHCS cohort study in Chongqing, China

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ABSTRACT

Epidemiological and experimental evidence for detrimental effects of cell phone use on semen quality is still equivocal. And that recruiting participants from infertility clinic not from general population may raise the possibility of a selection bias. To investigate effects of cell phone use on semen parameters in a general population,We screened and documented the cell phone use information of 794 young men from the Male Reproductive Health in Chongqing College students (MARHCS) cohort study in 2013, followed by 666 and 568 in 2014 and 2015, respectively. In the univariate regression analyses, we found that the daily duration of talking on the cell phone was significantly associated with decreased semen parameters, including sperm concentration [β coefficient = −6.32% per unit daily duration of talking on the cell phone (h); 95% confidence interval (CI), −11.94, −0.34] and total sperm count (−8.23; 95% CI, −14.38, −1.63) in 2013; semen volume (−8.37; 95% CI, −15.93, −0.13) and total sperm count (−16.59; 95% CI, −29.91, −0.73) in 2015]. Internet use via cellular networks was also associated with decreased sperm concentration and total sperm counts in 2013 and decreased semen volume in 2015. Multivariate analyses were used to adjust for the effects of potential confounders, and significant negative associations between internet use and semen parameters remained. Consistent but nonsignificant negative associations between talking on the cell phone and semen parameters persisted throughout the three study years, and the negative association was statistically significant in a mixed model that considered all three years of data on talking on the cell phone and semen quality. Our results showed that certain aspects of cell phone use may negatively affect sperm quality in men by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility.

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1. Introduction

Cell phones provide great convenience in our daily life, and they have become indispensable devices. However, they can emit radiofrequency electromagnetic waves (RF-EMWs) when they operate on a frequency band of hundreds MHz to thousands MHz. Although the stance is controversial, many epidemiological and experimental studies have reported that RF-EMWs have potential adverse effects on human health. They can interfere with nervous system function and cause headache, fatigue, impaired cognitive function, sleep disturbances, and an increased risk of tumor (Huber et al., 2000; Lonn et al., 2004; Oftedal et al., 2000); affect the cardiovascular system and increase resting blood pressure (Braune et al., 1998); and interfere with the endocrine system and decrease melatonin levels (Burch et al., 2002). Moreover, other studies have reported that cell phone use may lead to oxidative stress (De Iuliis et al., 2009; Oktem et al., 2005) and DNA strand breaks (Lai, 1996).

According to previous reports, approximately 15% of couples of reproductive age are infertile (Sharlip et al., 2002; Thonneau et al., 1991), and male factors account for 50% of these cases. We have focused on the effects of environmental and socio-psycho-behavioral factors on male reproductive health (Han et al., 2011; Zhou et al., 2014), and cell phone use is undoubtedly a contributing factor. However in the current literature, the possible effects of cell phone use on semen quality are inconclusive. For example, some studies demonstrated that cell phone use was associated with decrease the semen quality and parameters, including sperm count, motility, viability, and normal morphology (Agarwal et al., 2008; Fejes et al., 2005; Wdowiak et al., 2007). Further, experimental animal and cell studies have also demonstrated that cell phone radiation may affect testicular function and lead to genetic damage of germ cells (Dasdag et al., 1999; Liu et al., 2013). Oppositely, the

Abbreviations: MARHCS, the male reproductive health in Chongqing College students; RF-EMWs, radiofrequency electromagnetic waves; CASA, computer-aided sperm analysis; NP, nonprogressive; IM, immotility; SAR, specific absorption rate.

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other scientists did not find significant difference of semen parameters between non-users and users (Feijo et al., 2011). Moreover, we cannot ignore the fact that recruiting participants from a fertility clinic may cause a selection bias. Thus, the study regarding adverse effects of cell phone usage on semen quality in general population is urgently needed.

Besides, most of the above-mentioned studies did not sufficiently consider many potential confounding lifestyle factors, including smoking, drinking, coffee consumption, cola consumption, fried food consumption, the number of sexual partners, and use of condom, all of which have been found to be associated with semen parameters (Jurewicz et al., 2014; Li et al., 2011; McCready and Halkitis, 2008; Yang et al., 2015). The present study was an aspect of the Male Reproductive Health in Chongqing College Students (MARHCS) study conducted from 2013 to 2015, which aimed to investigate the potential effects of environmental and socio-psycho-behavioral factors on male semen quality. The objective of the present study was to report our findings regarding the adverse effects of cell phone use on semen quality in the general student population with a high percentage of cell phone acceptance and use, and help to promote the healthy use of cell phones.

2. Methods

2.1. Study population

The men including in the study were general college students in Chongqing. Professional lecture and propaganda were used to recruit volunteers. The trained staff explained that no discomfort or risks would arise from participation in the survey. At any time for any reason, participants could stop participating in the study. A total of 872 students from the university town were enrolled in the Male Reproductive Health in Chongqing College Students (MARHCS) study conducted since June 2013 (Yang et al., 2015). Informed consent was obtained from all volunteers. And the study was approved by approved by the Ethics Committees of Third Military Medical University. These participants completed two additional reproductive health surveys in 2014 and 2015. Individuals were excluded if they met any of the following criteria: <18 years old; <2 or >7 days of abstinence; a history of inflammation of the urogenital system, epididymitis or testicular injury; a history of incomplete orchiocatabasis; or a history of varicocele treatment; or if any of the following was detected by the urologist at the physical examination stage of the investigation: an absence of prominentia laryngea, pubis or testis; abnormal breasts or penis; epididymal knob; or varicocele.

2.2. Semen collection and analyses

Semen samples were collected in a special semen container via masturbation in a private room. Semen appearance was recorded by observation; semen volume was measured by weighing, assuming 1 g of weight equals to 1 ml of volume. After the samples underwent liquefaction at 37 °C in a water bath, semen parameters, including sperm concentration, total sperm count, and motility, were analyzed using computer-aided sperm analysis (CASA) according to WHO guidelines (2010). Sperm motility was graded as progressive (PR) motility, non-progressive (NP) motility, and immotility (IM) (Yang et al., 2015). To reduce the variation of assessment of sperm characteristics, all of the semen analyses were performed by one technician, who was well trained in semen analysis and participated in the Continuous Quality Control System (an external quality control system established on the basis of WHO guidelines) under the supervision of the Chongqing Science and Technology Commission.

2.3. Questionnaires

For interviewer–interviewing, the following information about the students' cell phone was collected via questionnaire: the number of cell phones owned, the presence of 3rd-generation (3G) function, the duration of cell phone use, the position in which they carry the cell phone, the daily duration that the cell phone is turned on (within the scope of 50 cm near the body), daily internet time or monthly data traffic via cellular networks, and daily time spent talking on the cell phone in the last three months. Because the values for the duration of cell phone use were originally obtained from the subjects in the form of a grouping variable, the median value selected by the participants was used to evaluate the total duration of cell phone use. According to the recommendation from the China Health Association, a volunteer would be defined as a current drinker if he averagely consumes 15 g or more ethanol per day. More detailed information about the study design and cell phone use can be found in another of our reports (Yang et al., 2015).

2.4. Statistical analysis

The semen parameters and the duration of cell phone use are presented as medians or percentiles because they always have nonnormal distributions. Both univariate and multivariate analyses were used to evaluate the associations between cell phone use and semen parameters. Nonparametric methods were chosen to compare the distributions of cell phone use among groups. A multiple linear regression analysis was performed to eliminate the effects of potential confounders including age, duration of abstinence, body mass index (BMI), smoking and drinking status, and the consumption of cola, coffee, and fried food. Furthermore, a mixed-effects linear regression model was used to globally assess all three years of data on cell phone use and semen parameters from 2013 to 2015. The Statistical Package for the Social Sciences (SPSS, Chicago, IL, USA) was used for the statistical analysis, and differences were considered significant if $P < 0.05$.

3. Results

3.1. Population characteristics and cell phone use

Using the inclusion criteria mentioned above, we selected 794, 666, and 568 men for the present study concerning the effects of cell phone use on semen quality in 2013, 2014, and 2015, respectively. All of the participants were undergraduate students with average ages of 20.4, 21.4, and 22.4 years, mean BMIs of 21.5, 21.6, and 22.2, and abstinence durations of 4.3, 4.2, and 4.1 days for 2013, 2014, and 2015, respectively. As Table 1 shows, approximately one-fifth of the subjects (21.5%, 22.1%, and 22.5% for 2013, 2014 and 2015) were current smokers. The proportions of current drinkers (74.3% and 74.5%) were increased in 2014 and 2015 compared with 2013 (47.2%). Coffee seemed to not be popular among the Chinese students. The amounts of cola and fried food that most of the subjects consumed did not exceed 3 bottles/wk and 1 time/wk, respectively.

For cell phone use, the median daily duration of having the phone on was 12.5 h for all three years. Talking and internet use via cellular networks were the two most common uses. The median daily talking durations were 0.5, 0.3, and 0.1 h for 2013, 2014, and 2015, respectively. The daily duration of internet use was 1.5 h in 2013. The monthly data traffic on the cellular network was 0.2 GB and 0.5 GB for 2014 and 2015, respectively.

3.2. Cell phone use and semen quality: univariate analysis

As Table 2 shows, in univariate regression analyses, the sperm concentration decreased by an average of 6.32% [95% confidence interval (CI), −11.94, −0.34] (absolute change: −4.35 million/ml; 95% CI, −8.23, −0.23) per unit increase in the daily duration of talking on the cell phone in 2013. The daily duration of talking on the cell phone was also significantly associated with sperm count (percentage change: -8.23; 95% CI, −14.38, −1.63; absolute change: −19.70 million; 95%

Table 1
Distributions of the study participant characteristics, cell phone use variables, and semen parameters.

Characteristic or variables	Values		
	2013 ($n = 794$)	2014 ($n = 666$)	2015 ($n = 568$)
Age (years)[a]	20.4 ± 1.2	21.4 ± 1.2	22.4 ± 1.2
BMI (kg/m^2)[a]	21.5 ± 3.2	21.6 ± 2.8	22.2 ± 2.9
Abstinence duration (days)[a]	4.3 ± 1.7	4.2 ± 1.4	4.1 ± 1.2
Tobacco smoking[b†]			
Never	593 (74.7)	483 (72.5)	414 (72.9)
Quit	30 (3.8)	35 (5.3)	26 (4.6)
Current	171 (21.5)	147 (22.1)	128 (22.5)
Alcohol drinking[b†]			
Never	409 (51.6)	130 (19.5)	122 (21.5)
Quit	10 (1.3)	41 (6.2)	22 (3.9)
Current	374 (47.2)	495 (74.3)	423 (74.5)
Coffee consumption[b]			
Never	605 (76.2)	471 (70.7)	426 (75.0)
<3 cups/wk	154 (19.4)	164 (24.6)	118 (20.8)
≥3 cups/wk	35 (4.4)	31 (4.7)	24 (4.2)
Cola consumption[b]			
Never	273 (34.4)	247 (37.1)	230 (40.5)
<3 bottles/wk	404 (50.9)	368 (55.3)	296 (52.1)
≥3 bottles/wk	117 (14.7)	51 (7.7)	42 (7.4)
Fried food consumption[b]			
<1 time/wk	436 (64.5)	371 (55.7)	342 (60.2)
1–2 times/wk	273 (15.5)	217 (32.6)	168 (29.6)
≥3 times/wk	85 (20.0)	78 (11.7)	58 (10.2)
Daily duration of having the cell phone on (h)[c]	12.5 (2.0, 22.5)	12.5 (2.7, 25)	12.5 (6.0, 25)
Daily duration of talking on the cell phone (h)[c]	0.5 (0.5, 1.5)	0.3 (0.1, 1.5)	0.1 (0.1, 0.8)
Internet use via cellular network[c]			
Daily duration in 2013 (h)[§]	1.5 (0.5, 6.5)	/	/
Monthly data traffic in 2014 and 2015 (GB)[§]	/	0.2 (0.02, 1)	0.5 (0.03, 2)
Volume (ml)[c]	3.4 (1.5, 6.7)	3.6 (1.8, 6.5)	3.6 (1.6, 6.6)
Sperm concentration (million/ml)[c]	54 (14, 194)	52 (14, 196)	42 (10, 154)
Total sperm count (million)[c]	184 (38, 627)	193 (43, 696)	159 (29, 510)
Progressive motility (%)[c]	55 (29, 83)	57 (27, 79)	57 (24, 78)

BMI = body mass index; h = hours; GB = gigabytes.
Values are presented as the mean ± SD[a], no. (%)[b] or median with 5th and 95th percentiles[c].
† Values are presented as daily duration (h) in 2013 and as monthly data traffic (GB) in 2014 and 2015.
§ Two subjects failed to report alcohol consumption data in 2013 and 2015, respectively, 1 failed to report tobacco smoking in 2014.

CI, −34.42, −3.90) in 2013 and with semen volume (percentage change: −8.37; 95% CI, −15.93, −0.13; absolute change: 0.32 ml; 95% CI, −0.61, −0.005) and total sperm count (percentage change: −16.59; 95% CI, −29.91, −0.73; absolute change: -33.76 million; 95% CI, −60.86, −1.49) in 2015. Moreover, the daily duration of internet use via cellular networks was strongly associated with decreased sperm concentration and total sperm count in 2013 (percentage change: −2.85; 95% CI, −4.66, −1.00; absolute change: -1.96 million/ml; 95% CI, −3.07, −0.69 and percentage change: −2.93; 95% CI, −5.00, −0.81; absolute change: −7.01 million; 95% CI, −11.97, −1.94, respectively) and with semen volume in 2015 (percentage change: −2.22; 95% CI, −3.80, −0.62; absolute change: 0.09 ml; 95% CI, −0.15, −0.02). We did not find conclusive relationships between the daily duration of having the phone on and semen parameters.

3.3. Multivariate analysis for cell phone use and semen parameters

As Table 3 shows, variables that were found to be associated with semen parameters as confounders in our other report were included in the multivariate analyses (Yang et al., 2015). After adjusting for age, duration of abstinence, tobacco and alcohol consumption, BMI, and coffee/cola/fried food consumption, we still observed that internet use via cellular networks was associated with decreased sperm concentrations and sperm count in 2013 (percentage change: −2.74; 95% CI, −4.53, −0.91; absolute change: −1.89 million/ml; 95% CI, −3.12, −0.47 and percentage change: -2.75; 95% CI, −4.76, −0.69; absolute change: −6.58 million; 95% CI, −11.39, −1.65, respectively) and decreased semen volume in 2015 (percentage change: −2.09; 95% CI, −3.64, −0.52; absolute change: −0.08 ml; 95% CI, −0.14, −0.02). Consistent negative associations between the daily duration of talking on a cell phone and semen parameters persisted throughout the three-year study period, although the associations were not statistically significant after adjustment. The time spent talking on a cell phone was also found to be significantly associated with decreased sperm counts in a mixed-effects model globally assessing all three years of data on cell phone use and semen quality for all three study years (percentage change: −4.87; 95% CI, −9.27, −0.27; absolute change: −11.29 million; 95% CI, −21.49, −3.83). The mixed model also revealed that the cell phone data traffic was associated with decreased semen volumes and decreased sperm counts (percentage change: −1.47; 95% CI, −2.74, −0.19; absolute change: -0.06 ml; 95% CI, −0.10, −0.01 and percentage change: −3.22; 95% CI, −5.85, −0.52; absolute change: −7.35 million; 95% CI, −13.36, −1.19, respectively).

Moreover, the users of 3G or more advanced telecommunication appeared to have higher sperm concentrations in 2014 (Supplemental Table 1). No valid associations were found between the other characteristics of cell phone use and sperm parameters.

4. Discussion

In today's society, cell phones have become an indispensable part of our lives. They provide great convenience for communication, information acquisition, and entertainment. However, their potential detrimental effects on male reproduction as a result of the RF-EMWs that they emit have also caused a growing concern. College students form a special population with a high percentage of digital device acceptance and use, and virtually all of them have at least one cell phone in the present study. As an aspect of the MARHCS study, research regarding the effects of cell phone use on semen quality was relevant and important.

Talking has been traditionally regarded as a type of cell phone use that influences semen quality. We confirmed a previous report on the negative effects of time spent talking on a cell phone on sperm concentration and total sperm count. In that study, daily cell phone use (for talking) was reported to be associated with decreased sperm counts in an infertility evaluation of 361 males (Agarwal et al., 2008). Another recent study also showed that talking for ≥1 h/day was associated with higher rates of abnormal semen concentration (Zilberlicht et al., 2015).

Furthermore, we found that internet use via cellular networks is another vital function of cell phones that has not received adequate attention in previous population studies. Because of increasing demands for web browsing, chatting (e.g., on QQ and WeChat in China), and viewing videos, cell phone users consume a large amount of data via cell phone networks every day. In the present study, the daily duration of internet use via cellular networks was found to be associated with decreased sperm concentrations and decreased sperm counts in 2013. Furthermore, data traffic, an accurate quantification of internet use via cellular networks, was found to be associated with decreased semen volumes and decreased sperm counts in 2014 and 2015. This result indicated that internet access via cellular networks should be sufficiently taken into account in future studies concerning the effects of cell phone use on semen quality.

3G-cell phones are believed to emit more electromagnetic radiation because they run on a higher frequency than 2G phones (Aydogan et al., 2015). In addition, 3G-cell phones can emit continuous RF-EMWs (Dogan et al., 2012). However, for the 2014 data from our study, those

Table 2
Unadjusted regression coefficients of cell phone use and semen parameters using a linear regression analysis.

Variables	Volume†, ml		Sperm concentration†, million/ml		Total sperm count†, million		Progressive motile sperm†,%	
	β coefficient	*P* value	β coefficient	*P* value	β coefficient	*P* value	β coefficient	*P* value
Daily duration of having the cell phone on (h)								
2013	0.19 (−0.24, 0.62)	0.390	−0.40 (−1.12, 0.32)	0.274	−0.33 (−1.14, 0.49)	0.433	0.17 (−0.13, 0.48)	0.269
2014	0.30 (−0.14, 0.75)	0.677	0.52 (−0.28, 1.33)	0.200	0.80 (−0.08, 1.70)	0.075	0.25 (−0.17, 0.66)	0.240
2015	−0.35 (−0.86, 0.17)	0.188	−0.28 (−1.21, 0.65)	0.554	−0.61 (−1.64, 0.43)	0.247	0.43 (−0.02, 0.88)	0.063
Daily duration of talking on the cell phone (h)								
2013	−2.08 (−5.60, 1.57)	0.259	**−6.32 (−11.94, −0.34)**	**0.039**	**−8.23 (−14.38, −1.63)**	**0.015**	−1.95 (−4.52, 0.69)	0.146
2014	0.79 (−2.88, 4.60)	0.677	−1.23 (−7.64, 5.62)	0.717	−0.33 (−7.44, 7.34)	0.931	1.08 (−2.37, 4.65)	0.545
2015	**−8.37 (−15.93, −0.13)**	**0.047**	−8.85 (−22.03, 6.55)	0.244	**−16.59 (−29.91, −0.73)**	**0.041**	−6.06 (−12.85, 1.27)	0.103
Internet use via cellular network								
Daily duration in 2013 (h)	0.32 (−0.82, 1.47)	0.587	**−2.85 (−4.66, −1.00)**	**0.003**	**−2.93 (−5.00, −0.81)**	**0.007**	0.48 (−0.33, 1.29)	0.249
Monthly data traffic in 2014 (GB)	−3.04 (−7.52, 1.65)	0.200	−1.70 (−9.75, 7.08)	0.695	−4.88 (−13.44, 4.54)	0.299	0.30 (−4.05, 4.84)	0.896
Monthly data traffic in 2015 (GB)	**−2.22 (−3.80, −0.62)**	**0.007**	−1.02 (−3.91, 1.95)	0.495	−3.20 (−6.34, 0.04)	0.053	0.57 (−0.86, 2.01)	0.437

h = hours; GB = gigabytes.
The results in bold indicate that the variable was significantly associated with changes in semen parameters ($P < 0.05$).
† Log10-transformed. The results are presented as back-transformed regression coefficients (percentage change per 1-unit increase in cell phone use) with 95% confidence intervals using a linear regression analysis without any adjustment.

who used 3G or more advanced telecommunication devices appeared to have a higher sperm concentration than those who used 2G devices. This unexpected finding may have occurred because better signals and advanced technology have enabled a decrease in the operating power of 3G-cell phones, thus decreasing electromagnetic radiation. However, the actual radiation dose remains to be determined.

A strength of the present study is its adjustment for potential confounders, including age, duration of abstinence, tobacco and alcohol consumption, BMI, and coffee/cola/fried food consumption, all of which have been considered valuable contributors to changes in semen quality in our other study and in previous studies (Jensen et al., 2010; Jurewicz et al., 2014; Kidd et al., 2001; Yang et al., 2015). In those studies and ours, age and lifestyle demonstrated strong relationships with semen quality; therefore, they should be adjusted for to evaluate the effects of other factors on semen quality. We also analyzed the potential effects of the number of sexual partners and use of condom on semen quality, both of which were suggested to predispose to sexually transmitted infections, thus causing alterations in seminal parameters (McCready and Halkitis, 2008). However, we did not find valid adverse relationship between them. In the present study, negative associations remain after adjustment for confounders. Collectively, this evidence indicates that certain aspects of cell phone use may negatively affect semen volume, sperm concentration, and sperm count.

These positive results may be interpreted to indicate that exposure to RF-EMWs from cell phones may affect certain testicular functions or structures and cause disorders of spermatogenesis (Kesari et al., 2010). The mechanism by which the EMWs emitted from cell phones cause damages to the testes remains unclear, but may be explained as follows. First, the optimal function of human testes requires a physiological temperature 2 °C lower than the body temperature, and an elevated temperature may be detrimental to spermatogenesis (Kandeel and Swerdloff, 1988; Zorgniotti, 1991); furthermore, several studies have shown that the damage that RF-EMWs cause to the spermatogenic epithelium and semen parameters may be related to an increase in testicular temperature (Saunders and Kowalczuk, 1981; Varma and

Table 3
Adjusted estimates (95% CI) of cell phone use and semen parameters using a multiple linear regression analysis and a mixed-effects linear regression model.

Variables	Volume†, ml		Sperm concentration†, million/ml		Total sperm count†, million		Progressive motile sperm†,%	
	β coefficient	*P* value	β coefficient	*P* value	β coefficient	*P* value	β coefficient	*P* value
Daily duration of talking on the cell phone (h)								
2013	−1.27 (−4.80, 2.38)	0.489	−4.53 (−10.24, 1.54)	0.141	−5.61 (−11.79, 1.01)	0.095	−2.46 (−5.00, 0.15)	0.065
2014	−0.11 (−4.71, 4.72)	0.965	−1.88 (−9.75, 6.69)	0.657	−1.79 (−10.41, 7.67)	0.700	0.17 (−4.18, 4.73)	0.939
2015	−7.46 (−15.03, 0.78)	0.075	−7.54 (−20.62, 7.70)	0.313	−14.38 (−27.43, 1.02)	0.066	−6.64 (−13.46, 0.72)	0.076
Mixed-effects model	−2.19 (−4.39, 0.06)	0.056	−2.90 (−6.91, 1.27)	0.170	**−4.87 (−9.27, −0.27)**	**0.038**	−0.77 (−2.71, 1.22)	0.445
Internet use via cellular network								
Daily duration in 2013 (h)	0.42 (−0.71, 1.56)	0.472	**−2.74 (−4.53, −0.91)**	**0.004**	**−2.75 (−4.76, −0.69)**	**0.009**	0.51 (−0.29, 1.32)	0.213
Monthly data traffic in 2014 (GB)	−3.11 (−7.65, 1.65)	0.197	1.36 (−6.92, 10.38)	0.756	−1.95 (−10.71, 7.68)	0.680	0.10 (−4.33, 4.74)	0.964
Monthly data traffic in 2015 (GB)	**−2.09 (−3.64, −0.52)**	**0.009**	−0.67 (−3.47, 2.21)	0.645	−2.72 (−5.69, 0.35)	0.082	0.57 (−0.85, 2.02)	0.431
Mixed-effects model (2014 and 2015)	**−1.47 (−2.74, −0.19)**	**0.025**	−1.65 (−4.04, 0.80)	0.185	**−3.22 (−5.85, −0.52)**	**0.020**	0.19 (−1.08, 1.48)	0.770

h = hours; GB = gigabytes.
The results in bold indicate that the variable was significantly associated with changes in semen parameters ($P < 0.05$).
Regression coefficients were adjusted for age, duration of abstinence, BMI, smoking and drinking status, and cola, coffee, and fried food consumption.
† Log10-transformed. The results are presented as back-transformed regression coefficients (percentage change per 1-unit increase in cell phone use) with 95% confidence intervals using a multiple linear regression analysis and a mixed-effects linear regression model.

Traboulay, 1975). Second, oxidative stress has also been considered a factor in the damage that cell phones cause to testicular functions or structures. Experimental studies, both in vivo and in vitro, suggest that cell phone radiation can increase the ROS level in spermatozoa (De Iuliis et al., 2009; Mailankot et al., 2009). Third, researchers have suggested that changes in the levels of sexual hormones may be another factor (Gutschi et al., 2011). Cell phone radiation has also been found to alter sperm cell membrane potential, signal transduction, apoptosis, and DNA damage (Agarwal et al., 2011). Unlike the thermal effects, these other changes can be considered nonthermal or EMW-specific effects, and they may contribute individually or jointly to the abovementioned damage to testes.

In contrast with the abovementioned studies (Agarwal et al., 2008; Sajeda and Al-Wattar, 2011), we did not find significant associations between cell phone use and sperm motility. Nevertheless, sperm motility is vital for male fertility and was the focus of many studies regarding effects of cell phone radiation on male reproduction. In a population study that enrolled 371 men undergoing infertility assessments, Fejes et al. (2005) reported the duration of cell phone ownership and the daily transmission time correlated negatively with the proportion of rapid progressive motile sperm but positively with the proportion of slow progressive motile sperm. An in vitro study showed that cell phone radiation caused a subtle decrease in rapid progressive and slow progressive sperm movement and also caused an increase in the non-motile category of sperm movement (Erogul et al., 2006).

Despite the positive results mentioned above, epidemiological and experimental evidence of detrimental effects of cell phone use on semen quality is still equivocal, even when taken from a meta-analysis (Dama and Bhat, 2013; Liu et al., 2014). A crude comparison between some recent cross-sectional studies and ours is shown in the Supplemental Table 2 (Feijo et al., 2011; Rago et al., 2013). We can observe the conflicting results of studies of cell phone radiation on sperm count, motility, viability, normal morphology. A variety of factors can affect human results and could contribute to the discordance among studies. First, the semen analysis criteria referenced by different studies differed because of ongoing changes to the related guidelines. Second, considerable variation exists in semen analysis methodologies and practices among different laboratories. Furthermore, the times and durations used to categorize cell phone use were diverse. For example, some studies included only the time spent talking on the cell phone, while other studies defined use patterns more broadly to include talking, internet use, or game playing. Similarly, variations in the dosage, duration, frequency, and pattern of exposure to RF-EMWs from cell phones may explain the differences between the results of human studies and the results of animal and in vitro studies. Compared with animal and in vitro studies, human studies provide the best evidence to clarify these issues; nonetheless, they are limited by difficulties with organization and performance. However, unified grouping variables or parameters for cell phone use and standardized experimental methods are critically needed in human studies.

There are limitations to this study. The cell phone use data were obtained via self-review, which raises the possibility of information bias. We did not consider the effects of the cell phone brand, which may result in differences in the specific absorption rate (SAR). The age of the study population vary within a small scale, and these positive results need be further validated in other populations with different ages. Sperm culture or urethral swabs should have been performed to exclude the effects of urogenital inflammation on semen quality. And the lack of hormonal and glycemic measurements weakened the exclusion of subjects with endocrine disorders such as abnormal thyroid and adrenal function and diabetes mellitus, which may alter sperm parameters. Nevertheless, the fact that the participants were recruited from the general student population and not from a typical infertility population made the study typical and relevant. Furthermore, the present study provides directions for further research.

5. Conclusion

Our results suggest that certain aspects of cell phone use may negatively affect sperm quality in men by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility. Especially, internet access via cellular networks should be sufficiently taken into account in future studies. We advise men with a pregnancy plan to avoid extensive use of cell phones. To identify the effects of cell phone use on semen quality, additional well-designed population studies are needed.

Conflict of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2016.02.028.

References

Agarwal, A., Deepinder, F., Sharma, R.K., Ranga, G., Li, J., 2008. Effect of cell phone usage on semen analysis in men attending infertility clinic: an observational study. Fertil. Steril. 89, 124–128.

Agarwal, A., Singh, A., Hamada, A., Kesari, K., 2011. Cell phones and male infertility: a review of recent innovations in technology and consequences. Int. Braz. J. Urol. 37, 432–454.

Aydogan, F., Unlu, I., Aydin, E., Yumusak, N., Devrim, E., Samim, E.E., Ozgur, E., Unsal, V., Tomruk, A., Ozturk, G.G., Seyhan, N., 2015. The effect of 2100 MHz radiofrequency radiation of a 3G mobile phone on the parotid gland of rats. Am. J. Otolaryngol. 36, 39–46.

Braune, S., Wrocklage, C., Raczek, J., Gailus, T., Lucking, C.H., 1998. Resting blood pressure increase during exposure to a radio-frequency electromagnetic field. Lancet 351, 1857–1858.

Burch, J.B., Reif, J.S., Noonan, C.W., Ichinose, T., Bachand, A.M., Koleber, T.L., Yost, M.G., 2002. Melatonin metabolite excretion among cellular telephone users. Int. J. Radiat. Biol. 78, 1029–1036.

Dama, M.S., Bhat, M.N., 2013. Mobile phones affect multiple sperm quality traits: a meta-analysis. F1000 Res. 2, 40.

Dasdag, S., Ketani, M.A., Akdag, Z., Ersay, A.R., Sari, I., Demirtas, O.C., Celik, M.S., 1999. Whole-body microwave exposure emitted by cellular phones and testicular function of rats. Urol. Res. 27, 219–223.

De Iuliis, G.N., Newey, R.J., King, B.V., Aitken, R.J., 2009. Mobile phone radiation induces reactive oxygen species production and DNA damage in human spermatozoa in vitro. PLoS One 4, e6446.

Dogan, M., Turtay, M.G., Oguzturk, H., Samdanci, E., Turkoz, Y., Tasdemir, S., Alkan, A., Bakir, S., 2012. Effects of electromagnetic radiation produced by 3G mobile phones on rat brains: magnetic resonance spectroscopy, biochemical, and histopathological evaluation. Hum. Exp. Toxicol. 31, 557–564.

Erogul, O., Oztas, E., Yildirim, I., Kir, T., Aydur, E., Komesli, G., Irkilata, H.C., Irmak, M.K., Peker, A.F., 2006. Effects of electromagnetic radiation from a cellular phone on human sperm motility: an in vitro study. Arch. Med. Res. 37, 840–843.

Feijo, C., Verza, S., Esteves, S.C., 2011. Lack of evidence that radiofrequency electromagnetic waves (RF-EMW) emitted by cellular phones impact semen parameters of Brazilian men. Hum. Reprod. 26, I139–I140.

Fejes, I., Závaczki, Z., Szöllősi, J., Koloszár, S., Daru, J., Kovács, L., Pál, A., 2005. Is there a relationship between cell phone use and semen quality? Arch. Androl. 51, 385–393.

Gutschi, T., Mohamad Al-Ali, B., Shamloul, R., Pummer, K., Trummer, H., 2011. Impact of cell phone use on men's semen parameters. Andrologia 43, 312–316.

Han, X., Zhou, N.Y., Cui, Z.H., Ma, M.F., Li, L.B., Cai, M., Li, Y.F., Lin, H., Li, Y., Ao, L., Liu, J.Y., Cao, J., 2011. Association between urinary polycyclic aromatic hydrocarbon metabolites and sperm DNA damage: a population study in Chongqing, China. Environ. Health Perspect. 119, 652–657.

Huber, R., Graf, T., Cote, K.A., Wittmann, L., Gallmann, E., Matter, D., Schuderer, J., Kuster, N., Borbely, A.A., Achermann, P., 2000. Exposure to pulsed high-frequency electromagnetic field during waking affects human sleep EEG. Neuroreport 11, 3321–3325.

Jensen, T.K., Swan, S.H., Skakkebaek, N.E., Rasmussen, S., Jorgensen, N., 2010. Caffeine intake and semen quality in a population of 2,554 young Danish men. Am. J. Epidemiol. 171, 883–891.
Jurewicz, J., Radwan, M., Sobala, W., Ligocka, D., Radwan, P., Bochenek, M., Hanke, W., 2014. Lifestyle and semen quality: role of modifiable risk factors. Syst. Biol. Reprod. Med. 60, 43–51.
Kandeel, F., Swerdloff, R., 1988. Role of temperature in regulation of spermatogenesis and the use of heating as a method for contraception. Int. J. Gynecol. Obstet. 27, 477–478.
Kesari, K.K., Kumar, S., Behari, J., 2010. Mobile phone usage and male infertility in wistar rats. Indian J. Exp. Biol. 48, 987–992.
Kidd, S.A., Eskenazi, B., Wyrobek, A.J., 2001. Effects of male age on semen quality and fertility: a review of the literature. Fertil. Steril. 75, 237–248.
Lai, H., 1996. Single-and double-strand DNA breaks in rat brain cells after acute exposure to radiofrequency electromagnetic radiation. Int. J. Radiat. Biol. 69, 513–521.
Li, Y., Lin, H., Cao, J., 2011. Association between socio-psycho-behavioral factors and male semen quality: systematic review and meta-analyses. Fertil. Steril. 95, 116–123.
Liu, C., Duan, W., Xu, S., Chen, C., He, M., Zhang, L., Yu, Z., Zhou, Z., 2013. Exposure to 1800 MHz radiofrequency electromagnetic radiation induces oxidative DNA base damage in a mouse spermatocyte-derived cell line. Toxicol. Lett. 218, 2–9.
Liu, K., Li, Y., Zhang, G., Liu, J., Cao, J., Ao, L., Zhang, S., 2014. Association between mobile phone use and semen quality: a systemic review and meta-analysis. Andrology 2, 491–501.
Lonn, S., Ahlbom, A., Hall, P., Feychting, M., 2004. Mobile phone use and the risk of acoustic neuroma. Epidemiology 15, 653–659.
Mailankot, M., Kunnath, A.P., Jayalekshmi, H., Koduru, B., Valsalan, R., 2009. Radio frequency electromagnetic radiation (RF-EMR) from GSM (0.9/1.8 GHz) mobile phones induces oxidative stress and reduces sperm motility in rats. Clinics 64, 561–565.
McCready, K.C., Halkitis, P.N., 2008. HIV serostatus disclosure to sexual partners among HIV-positive methamphetamine-using gay, bisexual, and other men who have sex with men. AIDS Educ. Prev. 20, 15–29.
Oftedal, G., Wilen, J., Sandstrom, M., Mild, K.H., 2000. Symptoms experienced in connection with mobile phone use. Occup. Med. (Lond.) 50, 237–245.
Oktem, F., Ozguner, F., Mollaoglu, H., Koyu, A., Uz, E., 2005. Oxidative damage in the kidney induced by 900-MHz-emitted mobile phone: protection by melatonin. Arch. Med. Res. 36, 350–355.
Rago, R., Salacone, P., Caponecchia, L., Sebastianelli, A., Marcucci, I., Calogero, A.E., Condorelli, R., Vicari, E., Morgia, G., Favilla, V., Cimino, S., Arcoria, A.F., La Vignera, S., 2013. The semen quality of the mobile phone users. J. Endocrinol. Investig. 36, 970–974.
Sajeda, S., Al-Wattar, Y.T., 2011. Effect of mobile phone usage on semen analysis in infertile men. Tikrit J. Pharm. Sci. 7, 77–82.
Saunders, R.D., Kowalczuk, C.I., 1981. Effects of 2.45 GHz microwave radiation and heat on mouse spermatogenic epithelium. Int. J. Radiat. Biol. Relat. Stud. Phys. Chem. Med. 40, 623–632.
Sharlip, I.D., Jarow, J.P., Belker, A.M., Lipshultz, L.I., Sigman, M., Thomas, A.J., Schlegel, P.N., Howards, S.S., Nehra, A., Damewood, M.D., Overstreet, J.W., Sadovsky, R., 2002. Best practice policies for male infertility. Fertil. Steril. 77, 873–882.
Thonneau, P., Marchand, S., Tallec, A., Ferial, M.L., Ducot, B., Lansac, J., Lopes, P., Tabaste, J.M., Spira, A., 1991. Incidence and main causes of infertility in a resident population (1,850,000) of three French regions (1988-1989). Hum. Reprod. 6, 811–816.
Varma, M.M., Traboulay Jr., E.A., 1975. Biological effects of microwave radiation on the testes of Swiss mice. Experientia 31, 301–302.
Wdowiak, A., Wdowiak, L., Wiktor, H., 2007. Evaluation of the effect of using mobile phones on male fertility. Ann. Agric. Environ. Med. 14, 169–172.
Yang, H., Chen, Q., Zhou, N., Sun, L., Bao, H., Tan, L., Chen, H., Zhang, G., Ling, X., Huang, L., Li, L., Ma, M., Wang, X., Zou, P., Peng, K., Liu, K., Liu, T., Cui, Z., Liu, J., Ao, L., Zhou, Z., Cao, J., 2015. Lifestyles associated with human semen quality: results from MARHCS cohort study in Chongqing, China. Medicine (Baltimore) 94, e1166.
Zhou, N., Cui, Z., Yang, S., Han, X., Chen, G., Zhou, Z., Zhai, C., Ma, M., Li, L., Cai, M., Li, Y., Ao, L., Shu, W., Liu, J., Cao, J., 2014. Air pollution and decreased semen quality: a comparative study of Chongqing urban and rural areas. Environ. Pollut. 187, 145–152.
Zilberlicht, A., Wiener-Megnazi, Z., Sheinfeld, Y., Grach, B., Lahav-Baratz, S., Dirnfeld, M., 2015. Habits of cell phone usage and sperm quality — does it warrant attention? Reprod. BioMed. Online.
Zorgniotti, A.W., 1991. Hypothesis to explain subfertile semen. In: Zorgniotti, A.W. (Ed.)-Temperature and Environmental Effects on the Testis vol. 286. Springer, New York, pp. 221–223.