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Association between BMI and semen quality: an observational study of 3966 sperm donors

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STUDY QUESTION: What is the relationship between abnormal BMI and semen quality?

SUMMARY ANSWER: Underweight was significantly associated with lower sperm concentration, total sperm number and total motile sperm count, while overweight was significantly associated with lower semen volume, total sperm number and total motile sperm count.

WHAT IS KNOWN ALREADY: Abnormal BMI has been associated with lower semen quality, but the results remain somewhat controversial. In addition, most previous studies have focused on the influence of obesity or overweight on semen quality, and evidence on the association between underweight and semen quality is rare.

STUDY DESIGN, SIZE, DURATION: This research was an observational study investigating 3966 sperm donors from a large sperm bank in Wuhan city, China. These donors passed the screening for sperm donation and underwent 29 949 semen examinations between 1 January 2013 and 9 April 2018.

PARTICIPANTS/MATERIALS, SETTING, METHODS: BMI was categorized into four groups: underweight ($<18.5\,\mathrm{kg/m^2}$), normal weight (18.5–$24.9\,\mathrm{kg/m^2}$), overweight (25–$29.9\,\mathrm{kg/m^2}$) and obese ($\geq 30\,\mathrm{kg/m^2}$). Semen volume, sperm concentration, total sperm number, total motility, progressive motility and total motile sperm count were determined by trained clinical technicians. Linear mixed models were used to conduct dose–response analyses between BMI and semen quality parameters.

MAIN RESULTS AND THE ROLE OF CHANCE: Underweight was significantly associated with a 3.0% (95% CI: 0.1%, 5.8%), 6.7% (1.9%, 11.3%) and 7.4% (2.2%, 12.4%) reduction in sperm concentration, total sperm number and total motile sperm count, respectively. Overweight was significantly associated with a 4.2% (1.6%, 6.8%), 3.9% (0.9%, 6.9%) and 3.6% (0.2%, 6.9%) reduction in semen volume, total sperm number and total motile sperm count, respectively. Non-linear models including continuous BMI as a natural cubic spline function yielded similar results.

LIMITATIONS, REASONS FOR CAUTION: Our study subjects were sperm donors who are typically young and healthy, and therefore not representative of the general male population. Caution should be paid in generalizing our results to other populations. Furthermore, we did not measure the donors' weight repeatedly along with each semen donation; instead, we only measured it once during the screening, which may cause bias due to the variations of weight across time.

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Introduction

Infertility continues to be a global public health issue and a major clinical concern, affecting 15% of reproductive-age couples (Mascarenhas *et al.*, 2012; Jiang *et al.*, 2015). It has been estimated that 70 million couples worldwide experience subfertility or infertility, and ~40% of cases are due to male factors (Sharlip *et al.*, 2002; Legare *et al.*, 2014; Salas-Huetos *et al.*, 2017). Poor semen quality is well recognized as a major condition that causes male infertility (Radwan *et al.*, 2016; Levine *et al.*, 2017). Recently, a rigorous and comprehensive meta-analysis of studies conducted between 1973 and 2011 reported that among men from western countries, sperm counts (measured either by sperm concentration or total sperm number) have declined by more than 50% (Levine *et al.*, 2017). Likewise, a variety of other studies have also reported that semen quality is continuously declining (Li *et al.*, 2016; Sengupta *et al.*, 2017; 2018). Although previous studies have demonstrated that some risk factors, including herbicides, pesticides and environmental pollutants, might be associated with decreased semen quality, the underlying causes of decreasing semen quality are largely uncertain (Xiao *et al.*, 2001; Sharpe, 2010; Bloom *et al.*, 2015; Chiu *et al.*, 2016).

Numerous studies have provided preliminary evidence that abnormal BMI is linked with various adverse health consequences, such as increased risks of metabolic and cardiovascular diseases (Pi-Sunyer, 2009). Recent studies have investigated the associations between abnormal BMI and semen quality, but the results remain inconsistent (Jensen *et al.*, 2004; Sermondade *et al.*, 2013; Eisenberg *et al.*, 2014; Tsao *et al.*, 2015). For example, Chavarro *et al.* suggested that the BMI ≥ 35 kg/m^2 was associated with lower ejaculate volume and lower total sperm number among 483 men attending an infertility clinic (Chavarro *et al.*, 2010). Wang *et al.* also reported that the increasing BMI appeared to be linked with lower total sperm number and lower sperm concentrations among 2384 subfertile men in northern China (Wang *et al.*, 2017). In contrast, a pooled meta-analysis of 31 studies, demonstrated that there were no significant associations between increased BMI and semen volume, sperm concentration or total sperm number (MacDonald *et al.*, 2010). On the other hand, evidence on the association between underweight and semen quality is still rare.

Taken together, the current evidence on the association between BMI and semen quality is limited and inconclusive, and further studies are warranted. In this study, we conducted a large observational study of 3966 healthy sperm donors from Wuhan city, China, and performed dose–response analyses to quantitatively assess the association between BMI and semen quality.

Materials and Methods

Study population

According to the standard protocol for human sperm banking initiated by the Chinese Ministry of Health (Ping *et al.*, 2011), a total of 3966 men aged 22–46 years were qualified as sperm donors at a large sperm bank in Wuhan, China between 1 January 2013 and 9 April 2018. All these sperm donors were in good health, both physically and psychologically, and had no history of genetic diseases. They also underwent and passed physical examinations and laboratory tests, which helped exclude individuals at high risk for sexually transmitted infections and genetic diseases. The donors' semen quality at screening fulfilled the following criteria: (i) fresh semen should have a liquefaction time of <60 min, sperm concentration of $\geq 60 \times 10^6$/ml, progressive motility of $\geq 32\%$, and normal morphology percent of $\geq 15\%$; and (ii) post-thaw semen should have a motility of $\geq 40\%$, total motile sperm count of $\geq 12 \times 10^6$, and a frozen–thaw survival rate of $\geq 60\%$. During the study period, the 3966 sperm donors underwent a total of 29 949 semen examinations with abstinence periods of 2–7 days.

Ethical approval

This work was approved by the Ethical Committee of Hubei Provincial Center for Disease Control and Prevention. The requirement for informed consent was waived by the committee, because the data used in this study were collected from previously routine clinical procedures and were anonymous to all research investigators.

Data collection

Structured questionnaires were used by trained physicians to collect information on demographics and lifestyle, including date of birth, ethnicity, education, smoking, marital status, season at semen collection and abstinence period. Height and weight were determined once using the same scale in the physical examination for each donor.

Semen examination

Semen sample examinations were conducted by trained clinical technicians. Semen samples were collected in a private room near the laboratory by masturbating into a sterile plastic container. The samples were then liquefied in an incubator (37°C) for 30 min and analyzed for semen volume, sperm concentration, and sperm motility within 60 min. Semen volume was measured by weighing. To assess sperm concentration and motility, 10 μl of each semen sample was placed in a Makler chamber, covered by a cover glass and then examined at ×200 magnification. Ten of the 100 squares in the microscope field were randomly scanned and the sperm number was recorded by a cytometer. Total motility was defined as the sum of progressive motility and non-progressive motility. We calculated total sperm number as semen volume multiplied by sperm concentration,

and calculated total motile sperm count as total sperm number multiplied by total motility.

Statistical analysis

BMI was calculated as weight (kg) divided by the square of height (m^2). According the guidelines of World Health Organization (WHO), BMI was categorized as underweight ($<18.5 \, kg/m^2$), normal weight ($18.5–24.9 \, kg/m^2$), overweight ($25–29.9 \, kg/m^2$) or obese ($\geq 30 \, kg/m^2$) (World Health Organization, 2000). To test the robustness of our results, we also grouped BMI based on the Chinese criteria: underweight ($<18.5 \, kg/m^2$), normal weight ($18.5–23.9 \, kg/m^2$), overweight ($24–27.9 \, kg/m^2$) and obese ($\geq 28 \, kg/m^2$) for sensitivity analyses (Zhou, 2002). All semen quality parameters were log-transformed before statistical analyses due to their approximate log-normal distributions, and were compared across BMI categories using repeated-measures ANOVA followed by Dunnett's tests.

We used linear mixed models with a subject-specific random intercept to examine the dose–response associations between BMI and semen quality parameters. The linear mixed model enabled us to account for correlations between repeated semen examinations for the same donor (Verbeke and Molenberghs, 2000). All models were adjusted for age, ethnicity, education, marital status, smoking, season at semen examination and abstinence period. Compared with normal weight, percent changes with the 95% CIs were estimated as $(e^{\beta} - 1) \times 100$ for semen quality parameters associated with underweight, overweight and obesity. Furthermore, we included a natural cubic spline function of BMI with 4 degrees of freedom in the linear mixed model to identify the non-linear dose–response relationship between continuous BMI and semen quality; percent changes were estimated for each semen quality parameter in relation to continuous BMI (minimum to maximum by $0.1 \, kg/m^2$) with the median BMI in normal weight subjects as the referent.

The robustness of our results was assessed by sensitivity analyses, including (i) using Chinese criteria for BMI category; (ii) restricting the analysis to non-smokers; and (iii) using the first semen donation sample only. All analyses were performed using R version 3.4.2 (R Core Team, 2017). All P values were two-sided, and $P < 0.05$ was considered as statistically significant.

Results

Characteristics of the study subjects by BMI category are summarized in Table 1. The mean age of sperm donors with normal weight was significantly higher than that of underweight subjects, and significantly lower than that of overweight subjects. About 68% of the subjects did not smoke, and the distribution of smoking did not vary significantly by BMI category. Mean BMI was 22.4 (SD: 2.8) kg/m^2, with 5.6% underweight, 76.8% normal, 16.6% overweight and 1.0% obese. The mean abstinence period was 5.4 (1.3) days, and there was no significant difference across BMI categories. The average intervals between the first and the last semen sample collection were 3.7 months, and 97.5% of the sperm donors completed their entire sperm donations within 1 year.

Compared with subjects with normal weight, the crude analyses showed that sperm concentration, total sperm number and total motile sperm count were significantly lower in underweight subjects (Table 2, all $P < 0.05$), while semen volume and total sperm number were significantly lower in overweight subjects (all $P < 0.05$). We did not observe any significant differences for total motility or progressive motility across BMI categories (all $P > 0.05$).

As shown in Table 3, underweight was significantly associated with a 3.0% (95% CI: 0.1%, 5.8%), 6.7% (1.9%, 11.3%) and 7.4% (2.2%, 12.4%) reduction in sperm concentration, total sperm number and total motile sperm count, respectively. Overweight was significantly associated with a 4.2% (1.6%, 6.8%), 3.9% (0.9%, 6.9%) and 3.6% (0.2%, 6.9%) reduction in semen volume, total sperm number and total motile sperm count, respectively. No significant associations were observed for sperm motility (all $P > 0.05$). Figure 1 shows the non-linear dose–response relationships between continuous BMI and semen quality parameters. When BMI was lower than the median BMI in normal weight subjects ($21.6 \, kg/m^2$), semen volume, sperm concentration, total sperm number, total motile sperm count, but not sperm motility, appeared to decrease monotonically with decreasing BMI. For BMI from 21.6 up to $30 \, kg/m^2$, semen volume, total sperm number and total motile sperm count were inversely associated with increasing BMI. No significant relationships were observed between BMI and sperm motility.

For BMI categories using Chinese criteria, the number of underweight, normal weight, overweight and obese subjects were 222 (5.6%), 2677 (67.5%), 923 (23.3%) and 144 (3.6%), respectively. Similar to results with the international BMI categories, underweight was inversely associated with sperm concentration, total sperm number and total motile sperm count, and overweight was significantly associated with lower semen volume and total sperm number (Supplementary Table S1). Among only the non-smokers, overweight was significantly associated with lower semen volume, total sperm number and total motile sperm count, which was consistent with that in all sperm donors (Supplementary Table S2, Fig. S1). In addition, we conducted analyses using the first sample for each sperm donor. The results showed that both underweight and overweight were significantly associated with lower semen volume, total sperm number and total motile sperm count (all $P < 0.05$), which was similar to the main analyses (Supplementary Table S3, Fig. S2).

Discussion

In this large observational study, we quantitatively investigated the association between BMI and semen quality in 3966 sperm donors from Wuhan, China, who underwent 29 949 semen examinations between 2013 and 2018. We found that underweight was inversely associated with sperm concentration, total sperm number and total motile sperm count, and overweight was significantly associated with lower semen volume, total sperm number and total motile sperm count. No significant associations were observed between obesity and semen quality in this population.

Current evidence on the relationship between abnormal BMI and semen quality remains controversial. Some studies have demonstrated that overweight or obesity is significantly linked with sperm concentration (Sekhavat and Moein, 2010; Hammiche et al., 2012; Belloc et al., 2014), total sperm number (Stewart et al., 2009; Chavarro et al., 2010; Sekhavat and Moein, 2010; Hammiche et al., 2012), sperm motility (Belloc et al., 2014) and sperm morphology (MacDonald et al., 2010; Shayeb et al., 2011). In comparison, other studies have not found significant associations (Duits et al., 2010; Eskandar et al., 2012; Eisenberg et al., 2014; Thomsen et al., 2014). Sermondade et al. (2013) conducted an updated systematic review and collaborative meta-analysis of 21 studies with 13 077 men from a general population

Table I Characteristics of the study subjects by BMI category.

Characteristic	All subjects	BMI category[a]			
		Underweight (n = 222)	Normal (n = 3046)	Overweight (n = 660)	Obese (n = 38)
Age, years					
<25	1291 (32.6)	103 (46.4)	1047 (34.4)	129 (19.6)	12 (31.6)
25–29	1356 (34.2)	75 (33.8)	1042 (34.2)	228 (34.5)	11 (28.9)
≥30	1319 (33.2)	44 (19.8)	957 (31.4)	303 (45.9)	15 (39.5)
Mean (SD)	28.5 (5.5)	26.8 (4.9)	28.2 (5.4)	30.3 (5.7)	28.7 (5.9)
Ethnicity					
Han	3844 (96.9)	216 (97.3)	2953 (96.9)	640 (97.0)	35 (92.1)
Others	122 (3.1)	6 (2.7)	93 (3.1)	20 (3.0)	3 (7.9)
Education					
High school and lower	1122 (28.3)	84 (37.8)	828 (27.2)	200 (30.3)	10 (26.3)
Junior college	1376 (34.7)	79 (35.6)	1067 (35.0)	219 (33.2)	11 (28.9)
Undergraduate and higher	1468 (37.0)	59 (26.6)	1151 (37.8)	241 (36.5)	17 (44.8)
Marital status					
Unmarried	2333 (58.8)	163 (73.4)	1853 (60.8)	296 (44.8)	21 (55.3)
Married	1367 (34.5)	45 (20.3)	982 (32.2)	323 (48.9)	17 (44.7)
Divorced	90 (2.7)	4 (1.8)	69 (2.3)	17 (2.6)	0 (0.0)
Living with partner	176 (4.4)	10 (4.5)	142 (4.7)	24 (3.7)	0 (0.0)
Current smoking status					
Non-smoker	2694 (67.9)	136 (61.3)	2100 (68.9)	433 (65.6)	25 (65.8)
Smoker	1272 (32.1)	86 (38.7)	946 (31.1)	227 (34.4)	13 (34.2)
Season at semen examination					
Winter (Dec, Jan, Feb)	5759 (19.2)	325 (17.9)	4446 (19.5)	936 (18.5)	52 (17.2)
Spring (Mar, Apr, May)	7257 (24.2)	331 (18.2)	5623 (24.7)	1234 (24.3)	69 (22.9)
Summer (Jun, Jul, Aug)	8309 (27.7)	524 (28.9)	6228 (27.4)	1472 (29.0)	85 (28.1)
Autumn (Sep, Oct, Nov)	8624 (28.9)	635 (35.0)	6465 (28.4)	1428 (28.2)	96 (31.8)
Abstinence period, days					
2–3	3108 (10.4)	201 (11.1)	2341 (10.3)	519 (10.2)	47 (15.6)
4–5	12 035 (40.2)	641 (35.3)	8648 (38.0)	2629 (37.9)	117 (38.7)
6–7	14 806 (49.4)	973 (53.6)	11 773 (51.7)	1922 (51.9)	138 (45.7)
Mean (SD)	5.4 (1.3)	5.4 (1.4)	5.4 (1.3)	5.4 (1.3)	5.2 (1.4)
No. semen samples per subject					
0–5	1537 (38.8)	80 (36.0)	1185 (38.9)	257 (38.9)	15 (39.5)
6–10	1504 (37.9)	77 (34.7)	1171 (38.4)	244 (37.0)	12 (31.6)
>10	925 (23.3)	65 (29.3)	690 (22.7)	159 (24.1)	11 (28.9)

Data are shown as number (percentage, %), if not specified.
[a]BMI was categorized using the WHO criteria: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2) and obese (≥30 kg/m^2).

or those attending fertility clinics, and did not observe a linear relationship between BMI and sperm concentration. However, they found that overweight and obesity were significantly associated with an increased risk of abnormal total sperm number, defined as azoospermia or oligozoospermia.

Only a few studies have examined the association between underweight and semen quality, because underweight subjects generally account for only a small proportion of study populations. Early in

2004, Jensen *et al.* studied 1558 Danish young men who attended a compulsory physical examination for military service between 1996 and 1998, and found that underweight (defined as BMI < 20 kg/m^2) subjects had a significant reduction in sperm concentration and total sperm number, respectively (Jensen *et al.*, 2004). Later in 2007, Qin *et al.* investigated 990 fertile men from a general population in 2001 and 2002, and reported that underweight was significantly associated with a lower sperm concentration and total sperm number (Qin *et al.*,

Table II Distribution of semen quality parameters by BMI category.

Characteristic	All subjects	BMI category[a]			
		Underweight (n = 1815)	Normal (n = 22 762)	Overweight (n = 5070)	Obese (n = 302)
Semen volume, ml	3.0 (1.9)	2.6 (1.8)	3.0 (1.9)	2.6 (1.8)[b]	2.6 (2.0)
Sperm concentration, 10^6/ml	62.0 (7.0)	60.0 (15.0)[b]	62.0 (7.0)	62.0 (7.0)	63.0 (8.0)
Total sperm number, 10^6	168.0 (110.0)	156.0 (95.6)[b]	170.0 (110.0)	163.2 (99.5)[b]	166.5 (112.0)
Total motility, %	66.0 (6.0)	65.0 (7.0)	66.0 (6.0)	66.0 (7.0)	65.0 (6.0)
Progressive motility, %	61.0 (4.0)	60.0 (8.0)	61.0 (4.0)	61.0 (4.0)	61.0 (4.0)
Total motile sperm count, 10^6	107.2 (70.6)	101.2 (65.3)[b]	108.0 (72.5)	105.1 (66.4)	109.1 (75.5)

Data are shown as median (IQR). 'n' refers to the number of subjects in each BMI category.
[a]BMI was categorized using the WHO criteria: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2) and obese (≥30 kg/m^2). The number of underweight, normal weight, overweight and obese subjects were 222, 3046, 660 and 38, respectively. Semen parameters across BMI category were compared using repeated-measures ANOVA followed by Dunnett's tests.
[b]Compared with normal, $P < 0.05$.

Table III Estimated percent changes and 95% CIs for semen quality parameters associated with underweight, overweight and obesity compared with normal weight[a].

Characteristic	Underweight (n = 1815)		Normal (n = 22 762)	Overweight (n = 5070)		Obese (n = 302)	
	Percent change (95% CI)	P	Percent change (95% CI)	Percent change (95% CI)	P	Percent change (95% CI)	P
Semen volume, ml	−3.6 (−7.7, 0.7)	0.10	0 (ref.)	−4.2 (−6.8, −1.6)	0.002	6.0 (−4.3, 17.5)	0.27
Sperm concentration, 10^6/ml	−3.0 (−5.8, −0.1)	0.042	0 (ref.)	0.3 (−1.5, 2.2)	0.72	1.7 (−5.1, 9.0)	0.63
Total sperm number, 10^6	−6.7 (−11.3, −1.9)	0.007	0 (ref.)	−3.9 (−6.9, −0.9)	0.012	7.1 (−4.6, 20.9)	0.24
Total motility, %	−0.7 (−2.1, 0.7)	0.32	0 (ref.)	0.3 (−0.6, 1.3)	0.46	1.1 (−2.2, 4.6)	0.51
Progressive motility, %	−0.6 (−2.1, 1.0)	0.47	0 (ref.)	0.6 (−0.4, 1.6)	0.25	1.1 (−2.6, 4.9)	0.56
Total motile sperm count, 10^6	−7.4 (−12.4, −2.2)	0.006	0 (ref.)	−3.6 (−6.9, −0.2)	0.036	8.9 (−4.3, 24.0)	0.20

N refers to the number of subjects in each BMI category.
[a]BMI was categorized using the WHO criteria: underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2) and obese (≥30 kg/m^2). The number of underweight, normal weight, overweight and obese subjects were 222, 3046, 660 and 38, respectively.
Linear mixed models were used to estimate percent changes and 95% CIs with adjustment for age, ethnicity, education, smoking, marital status, abstinence period and season.

2007). Consistent with our results, both of the two studies found that underweight was inversely associated with sperm concentration and total sperm number, and that there were no significant associations between underweight and sperm motility or semen volume. Similarly, the recent meta-analysis by Sermondade et al. observed an increased risk of abnormal sperm concentration associated with underweight, although the association between underweight and risk of abnormal total sperm number was insignificant.

Several possible reasons may account for the inconsistent associations between BMI and semen quality. First, study subjects have rarely been randomly selected in the general population due to low participation rates under 30% (Rolland et al., 2013); instead, previous studies have typically enrolled fertile men or infertile men undergoing assisted reproductive technology. We selected sperm donors who were relatively healthier in this study, which might lead to limited generalizability and yield different results (Sermondade et al., 2013). However, choosing sperm donors as the subjects has been a practical alternative to conduct semen quality studies (Sokol et al., 2006). Second, some

studies have used self-reported measures of BMI, which are less accurate and may result in biased associations (Aggerholm et al., 2008; Hammoud et al., 2008). Third, most studies have used a single semen sample, which may inadequately represent a man's testis function at any given time (Amann, 2009; Hammiche et al., 2012; Tsao et al., 2015). Finally, relatively small sample sizes, especially for underweight subjects in previous studies and obese objects in our study, may not provide sufficient statistical power to detect significant associations.

The pathophysiology behind the association between abnormal BMI and semen quality is unclear and likely complex. Overweight and obesity have been shown to affect the GnRH–FSH/LH pulse, which may impair Leydig or Sertoli cell functions and interfere with the release of sex hormones and production of mature sperm (Hammoud et al., 2008). In comparison, the relationship between underweight and lower semen quality may be due to undernutrition, which is known to have adverse effects on male reproductive hormone (Rocha-de-Melo and Guedes, 1997; Ramos et al., 2000; Santos et al., 2004). Undernutrition is associated with a decreased testosterone level (Chik
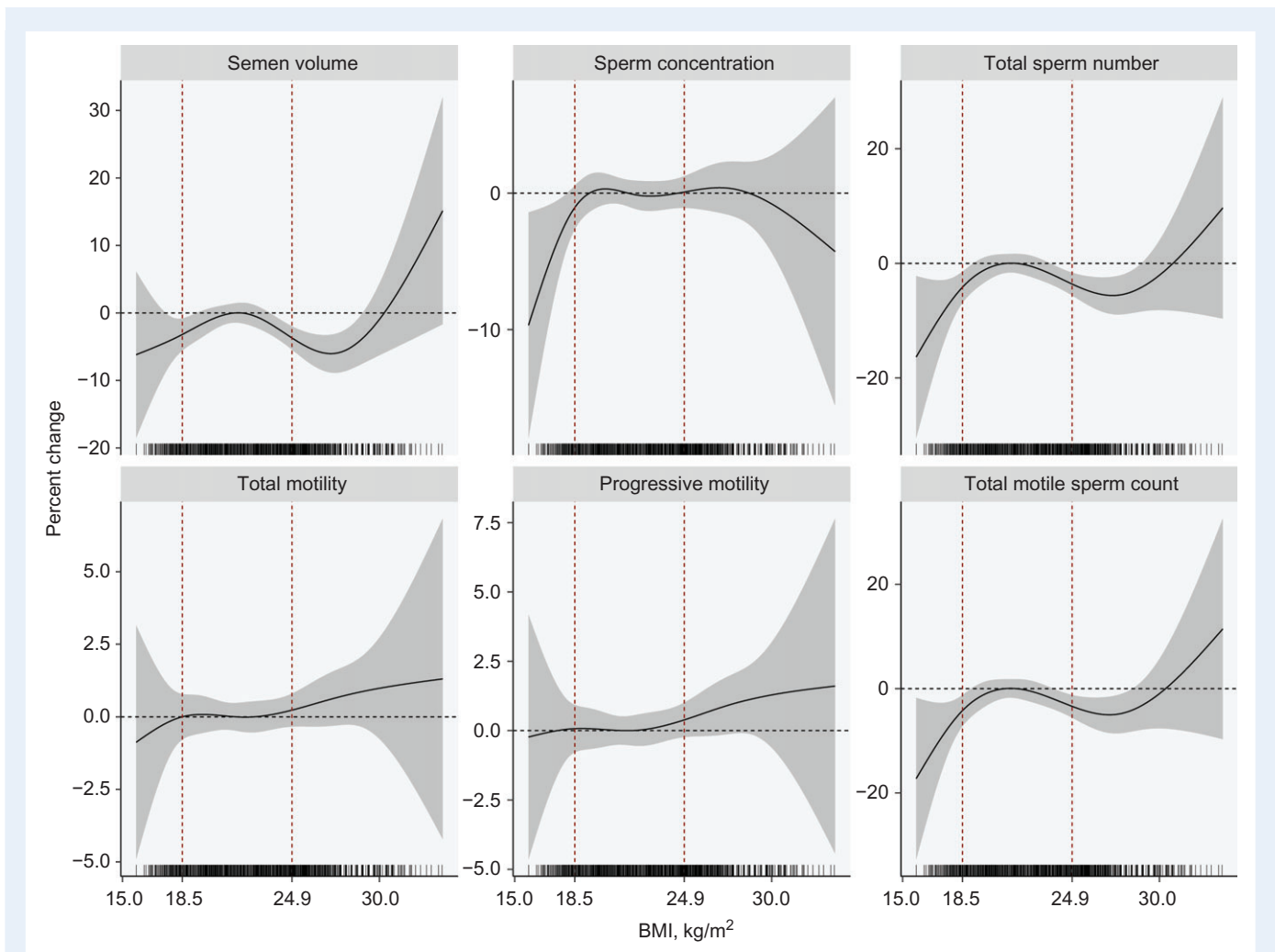
Figure 1 Non-linear dose–response curves between continuous BMI and semen quality parameters. The BMI was included as a natural cubic spline function in the linear mixed model, adjusting for age, ethnicity, education, smoking, marital status, abstinence period and season. For better interpretation, the percent changes were estimated relative to the median value of normal weight (21.6 kg/m^2). The vertical dotted lines gave the range of normal weight (18.5–24.9 kg/m^2).

et al., 1989), which may be a major reason for poor spermatogenesis through depriving the developing sperm of the signals required for normal maturation (Amory and Bremner, 1998).

Our findings have important public health implications. As the major reason for male infertility, poor semen quality has drawn much concern globally. Our study provides evidence that both underweight and overweight may adversely affect semen quality. It was estimated that the global prevalence of underweight for male adults in 2016 was 8.5%, and 39% for overweight (World Health Organization, 2016). These findings highlights the importance of maintaining a normal weight for men.

One major strength of our study is the large sample size with an average of eight repeated measures of semen quality, which allows us to account for within-subject variability and provides robust estimates. In addition, we firstly examined the non-linear dose–response relationship between BMI and semen quality. On the other hand, several limitations need to be discussed. First, our study subjects were sperm donors who were typically young and healthy, and were unable to

represent the general male population. Caution should be used when generalizing our results to other populations. Second, we did not measure the donors' weight repeatedly along with each semen quality test; instead, we only measured once during the screening, which may lead to misclassification due to the variations of weight across time. However, the BMI was unlikely to change dramatically, because BMI was measured at the time of first semen sample, and the whole duration of sperm donation (from the first semen sample to the last semen sample) for the studied sperm donors was only an average of 3.7 months. Third, although we adjusted for all available potential confounders, there is still the possibility that residual or unmeasured confounding partly contributed to the associations. Finally, BMI cannot distinguish between body fat and muscle mass. However, we did not collect information on physical activity or waist circumstance. Men who are physically active and muscular tend to be healthier and tip into overweight or obese status, which may lead to underestimation on the association between overweight/obesity and semen quality.

In conclusion, we found that underweight and overweight were both significantly associated with lower semen quality. Our findings highlight the importance of maintaining a normal weight for men.

Supplementary data

Supplementary data are available at *Human Reproduction* online.

Authors' roles

All authors fulfill the criteria for authorship. Y.L. and T.M. designed the study, participated in data collection and analyses and revised the article. J.M. and L.W. conducted statistical analysis, summarized the results and drafted the article. Y.Z. participated in data analyses and interpretation and revised the article. C.X., H.Z. and Z.P. collected the clinical data, validated the data and revised the article. W.B. contributed significantly to the interpretation of the results and revised the article.

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Conflict of interest

None of the authors has any conflict of interest to declare.

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