Hindawi
Andrologia
Volume 2023, Article ID 9142450, 7 pages
https://doi.org/10.1155/2023/9142450

Research Article

The Impact of Heat Exposure, Obesity, and Physical Activity on Sperm Quality: An Observational Study

Eriana Melinawati [1,2], Teguh Prakosa [1,2], Uki Retno Budihastuti [1,2], Mulyoto Pangestu [3], Affi Angelia Ratnasari [1,2], and Puji Aris Rismawan [1,2]

[1]Faculty of Medicine, Sebelas Maret University, Surakarta, Jawa Tengah, Indonesia
[2]Moewardi General Hospital, Surakarta, Jawa Tengah, Indonesia
[3]Education Program in Reproduction and Development, Department of Obstetrics and Gynecology, Monash Clinical School, Monash University, Clayton, VIC, Australia

Correspondence should be addressed to Eriana Melinawati; eriana.melinawati@staff.uns.ac.id

Received 13 May 2023; Revised 5 September 2023; Accepted 16 September 2023; Published 4 October 2023

Academic Editor: Raul Sanchez

In Indonesia, 12% or 3 million married couples suffer from infertility, with 36% of cases caused by male factors. Heat exposure, obesity, and lack of physical activity can decrease sperm quality by inducing oxidative stress and inflammation and altering the hypothalamic–pituitary–gonadal axis mechanisms. This study investigated the impact of heat exposure, obesity, and physical activity on sperm quality. This study employed an analytical observational design with a cross-sectional approach, conducted at the Sekar Fertility Clinic, Dr. Moewardi General Hospital. Sixty samples were analyzed using bivariate, multivariate, and $\chi 2$ tests or Fisher exact test with a 95% confidence interval and $p < 0.05$. Exposure to heat was found to increase the risk of low-sperm concentration by 74.09 times ($p = 0.001$), obesity increased the risk of low-sperm concentration by 16.74 times ($p = 0.013$), and low-sperm motility by 6.12 times ($p = 0.014$), and lack of physical activity increased the risk of low-sperm concentration by 27.23 times ($p = 0.033$). Heat exposure, obesity, and physical inactivity are associated with low-sperm concentration, and obesity is also associated with low-sperm motility.

1. Introduction

Infertility is a prevalent issue that has a global impact on millions of individuals in their reproductive years. Not only does it significantly affect those who experience it, but it also affects their families and communities. It is a severe public health issue that affects a considerable proportion of couples worldwide, with estimates suggesting that around 8%–12% of couples experience infertility [1, 2]. Sperm quality, a key determinant of male fertility, can be influenced by various environmental and lifestyle factors, including heat exposure, obesity, and physical inactivity [3].

Exposure to excessive heat can reduce sperm motility by decreasing mitochondrial activity and reducing the body's adenosine triphosphate (ATP) levels. Mitochondria are essential in providing energy for sperm movement and interaction with the egg cell. In addition, a temporary increase in scrotal temperature can also significantly affect the process of spermatogenesis. A brief rise in scrotal temperature can result in a reversible drop in proteins essential for spermatogenesis, gamete interaction, and sperm motility. Therefore, excessive heat exposure to the scrotum can cause decreased sperm motility and disruption to spermatogenesis. This can affect male fertility and complicate the process of fertilization [4–6].

Obesity, a growing problem worldwide, has also been linked to male fertility primarily due to chronic inflammation, which can disrupt various bodily systems and processes such as the hypothalamus–pituitary–adrenal (HPA) axis, steroidogenesis, spermatogenesis, and semen quality [7]. Obesity has a negative impact on male fertility by disrupting the hypothalamic–pituitary–gonadal (HPG) axis and altering testosterone and estrogen levels. This imbalance in the rank of testosterone and estrogen can significantly impact the process of spermatogenesis [8]. Physical inactivity, another common lifestyle factor, has been shown to reduce sperm quality by disrupting the hypothalamic–pituitary–gonadal axis and increasing oxidative stress [9]. A sedentary lifestyle and lack of physical activity are associated with idiopathic male infertility [10]. Furthermore, decreased physical activity is associated with obesity, being overweight, as well as decreased sperm quality and causing DNA damage [11]. Conversely, exercising regularly and within reasonable limits can improve sperm quality [12].

Despite the potential impact of these factors on male fertility, few studies have investigated their combined effects on sperm quality. Therefore, this observational study examined the impact of heat exposure, obesity, and physical activity on sperm quality among Indonesian men attending a fertility clinic. The findings of this study could provide insights into the modifiable factors that contribute to male infertility and inform strategies for improving reproductive health in this population.

2. Materials and Methods

2.1. Study Design. This study utilized an analytical observational using a cross-sectional approach. The study was conducted at the Sekar Fertility Clinic, Dr. Moewardi General Hospital, from January to July 2022.

2.2. Participants. Sixty sperm samples were collected from male patients who came to Sekar Fertility Clinic, Dr. Moewardi General Hospital, who met the inclusion criteria.

Inclusion criteria: sperm samples from male patients examined by a team of fertility doctors, patients have performed sexual abstinence within 2–7 days, sperm had to be placed in a container provided by Sekar Fertility Clinic, Dr. Moewardi General Hospital, and the volume of ejaculate cement was at least 1 ml.

Exclusion criteria: patients with a history of mumps and orchitis, patients unwilling to participate in the study, untreated tuberculosis patients, and patients who took testosterone in the last 3 months.

2.3. High-Temperature Exposure. High-temperature exposure in this study referred to the high temperature of the sun experienced by respondents while riding a bicycle or motorcycle and the elevated temperatures experienced while riding a car with an engine located beneath the driver's seat. The duration of exposure to high temperatures was measured in minutes per week. Respondents who used other transportation were not exposed to high temperatures. Therefore, the duration of exposure to high temperatures is grouped into: not exposed: less than 75 min per week, low exposure: 75–150 min per week, moderate exposure: 150–225 min per week, and high exposure: more than 225 min per week.

2.4. Obesity Classification. Obesity is a body mass index (BMI) exceeding 30 kg/m^2. Height and weight data in centimeters and kilograms were used to calculate BMI. According to the World Health Organization (WHO) recommendations [13], BMI categories were as follows: 18–24.9 (normal body weight), 25–29.9 (overweight), 30–34.9 (obesity Class 1), 35–39.9 (obesity Class 2), and above 40 (morbid obesity). Individuals with normal weight and overweight were categorized as nonobese, while those with a BMI greater than 30 kg/m^2 were classified as obese.

2.5. Physical Activity. Physical activity refers to any activity that requires physical effort. The data collection tool used in this study was the international physical activity questionnaire (IPAQ). High, medium, and low-physical activities were performed within 7 days. The values for high, medium, and low-physical activities in minutes are multiplied by the respective metabolic equivalent of task (MET) constants according to the formula [14]. The MET constants for heavy activity are eight METs, moderate activity is four METs, and walking is 3.3 METs. Respondents will be asked seven questions about physical activities, categorized as high, medium, and low.

The formula for calculating the score for physical activity is as follows:

Total MET = low (4 MET × minutes × days) + medium activity (3.3 MET × minutes × days) + high activity (8 MET × minutes × days) [15].

The classification is then as follows:

Low-physical activity: 600 MET minutes per week

Medium-physical activity: >600–3000 MET minutes per week

High-physical activity: >3,000 MET minutes per week

The total score for physical activity is calculated in MET minutes per week. This study categorized the measurement results into two groups: low-physical activity and medium/high-physical activity. The data were classified as categorical variables.

2.6. Sperm Concentration. The sperm concentration is calculated using the improved Neubauer counting chamber. It is measured after sperm liquefaction, which occurs within 30 min after ejaculation. With a dilution factor 20, the sperm is observed in the Neubauer counting chamber using grids 5, 4, and 6. The sperm concentration is millions per milliliter (million/ml). The formula for calculating sperm concentration [16] is as follows:

concentration = $N/n \times 1/20 \times$ dilution factor,

N: number of spermatozoa counted,

n: number of rows counted,

1/20: constant of the counting chamber,

dilution factor: the degree of dilution performed.

The normal range for sperm count is 15–200 million/ml of semen. A low-sperm count (abnormal) is considered when it is less than 15 million/ml or when the total sperm count is less than 39 million per ejaculation [16, 17].

2.7. Sperm Motility. Sperm motility is observed after the sperm has undergone liquefaction within 30 min after ejaculation. The sperm is thoroughly mixed until homogeneous, and then 10 μl of semen is dropped onto an object glass. It is spread evenly and covered with a coverslip, ensuring a chamber height of 20 μm. The sample is then allowed to stand for 60 s before observation. A light microscope with a magnification of 200 or 400 times was used for observation. At least 200 spermatozoa are counted for each replicate. The observations are measured and categorized in percentages (%) according to the criteria defined by WHO in 2010:

(a) Progressive motility (PR): spermatozoa exhibiting active forward movement in a straight line or large circles.
(b) Nonprogressive motility (NP): all movements other than progressive motility, including rotating in place, vibrating in place, or only tail movement.
(c) Immotility (IM): no movement observed.

According to the WHO criteria from 2010, motility is considered normal if the progressive motility (PR) is greater than 32% or the total motility (PR + NP) is greater than 40% [16, 17].

2.8. Sperm Morphology. Sperm morphology is observed in a smear preparation. The smear is made and stained using Giemsa or Wright stain. Observation is done using a light microscope at a magnification of 1,000 times using immersion oil. At least 200 spermatozoa are observed in each replicate. The number of abnormal spermatozoa and total spermatozoa observed is counted and compared, expressed as a percentage (%), according to the criteria defined by WHO in 2010.

Normal sperm morphology is characterized by an oval head shape, with the acrosome covering 40%–70% of the head area. It should have a neck, midpiece, and no abnormalities in the tail or cytoplasmic droplets exceeding 50% of the size of the sperm head. The percentage of normal sperm morphology is calculated by comparing the number of normal sperm morphology to the total number of spermatozoa observed, and it should be above 4% [16, 17].

2.9. Data Analysis. The normality of the data was assessed using the Kolmogorov–Smirnov test. Bivariate and multivariate analyses were conducted to evaluate correlations. Logistic regression analysis was performed for statistical tests, considering the nonnormal data distribution for independent and dependent variables. Data analysis were carried out using SPSS version 23.0.

2.10. Ethical Considerations. The research study obtained ethical clearance from the Health Research Ethics Committee of Dr. Moewardi General Hospital under number 851/VI/HREC/2022. This approval indicates that the research protocol meets established ethical guidelines and regulations. As an essential part of the ethical approval process, all participants in the study provided informed consent.

3. Results

Based on Table 1 above, exposure to high temperatures is mainly in the nonexposed category (71.7%), BMI is mostly in the normal weight category (53.3%), and physical activity is mainly in the low category (51.7%). Where daily work activities often are the reason for physical activity in this study. Most subjects spend time sitting while working.

Table 1: Summary of research subject characteristics.

Variable	Frequency	% ($n = 60$)
Age (years)		
20–30	21	35
31–40	31	51.7
>40	8	13.3
Education (years)		
<12	8	13.3
>12	52	86.7
High-temperature exposure (minutes per week)		
Not exposed (<75)	43	71.7
Low exposure (75–150)	6	10
Medium exposure (150–225)	8	13.3
High exposure (>225)	3	5
BMI (kg/m^2)		
Normal weight (18–24.9)	32	53.3
Overweight (25–29.9)	12	20
Obesitas class 1 (30–34.9)	15	25
Obesitas class 2 (35–39.9)	1	1.7
Physical activity (MET minutes per week)		
Low (600)	31	51.7
Medium (>600–3,000)	20	33.3
High (>3,000)	9	15

Note: BMI: body mass index, MET: Metabolic equivalent of task.

The results of statistical analysis in Table 2 demonstrate that exposure to high temperature with medium/high intensity in the bivariate analysis had an OR = 88.00 (95% CI = 9.24–838.40; $p < 0.001$), and in the multivariate analysis, it had an OR value of 74.09 (95% CI = 5.83–941.30; $p = 0.001$). This indicates that exposure to a high temperature significantly affects sperm concentration statistically with a $p < 0.05$. Furthermore, based on the data analysis results, obesity in the bivariate analysis had an OR value of 8.14 (95% CI = 2.20–30.19; $p = 0.002$), and in the multivariate analysis, it had an OR value of 16.74 (95% CI = 1.81–155.20; $p = 0.013$). Obesity significantly affects sperm concentration statistically with a $p < 0.05$. In addition, physical activity in the bivariate analysis statistically poses a 9.75-fold risk to sperm concentration (OR = 9.75; 95% CI = 1.96–48.47; $p = 0.002$), and in the multivariate analysis, physical activity poses a 27.23-fold risk to sperm concentration (OR = 27.23; 95% CI = 1.31–566.25; $p = 0.033$). This implies that a lack of physical activity significantly affects the risk of sperm concentration statistically with a $p < 0.05$.

The results of sperm motility research in Table 3 show that exposure to high temperatures with medium/high intensity in bivariate analysis (OR = 7.78; CI 95% = 1.87–32.36; $p = 0.005$) and multivariate analysis (OR = 3.87; CI 95% = 0.81–18.35; $p = 0.089$). Thus exposure to high temperatures in multivariate analyses is not the dominant variable that affects sperm motility. Obesity in the bivariate analysis (OR = 6.80; CI 95% = 1.90–24.35; $p = 0.006$) and in multivariate analysis (OR = 6.12; CI 95% = 1.45–25.78; $p = 0.014$). Thus obesity has a significant effect on sperm motility with a value of $p < 0.05$. In bivariate analysis, low-physical activity

Table 2: Association between high-temperature exposure, BMI, physical activity, and sperm concentration.

Variable	Concentration		Bivariate			Multivariate		
	Abnormal	Normal	OR	CI 95%	p Value	OR	CI 95%	p Value
High-temperature exposure								
Medium/high	10 (66.7%)	1 (2.2%)	88	9.24–838.40	<0.001*	74.09	5.83–941.30	0.001*
Low	5 (33.3%)	44 (97.8%)						
BMI								
Obesity	9 (60%)	7 (15.6%)	8.14	2.20–30.19	0.002*	16.74	1.81–155.20	0.013*
Nonobesity	6 (40.0%)	38 (84.4%)						
Physical activity								
Low	13 (86.7%)	18 (40.0%)	9.75	1.96–48.47	0.002*	27.23	1.31–566.25	0.033*
Medium/high	2 (13.3%)	27 (60%)						

Note: BMI: body mass index; *Significant p value < 0.05.

Table 3: Association between high-temperature exposure, BMI, physical activity, and sperm motility.

Variable	Motility		Bivariate			Multivariate		
	Abnormal	Normal	OR	CI 95%	p Value	OR	CI 95%	p Value
High-temperature exposure								
Medium/high	7 (43.8%)	4 (9.1%)	7.78	1.87–32.36	0.005*	3.87	0.81–18.35	0.089
Low	9 (56.3%)	40 (90.9%)						
BMI								
Obesity	9 (56.3%)	7 (15.9%)	6.8	1.90–24.35	0.006*	6.12	1.45–25.78	0.014*
Nonobesity	7 (43.8%)	37 (84.1%)						
Physical activity								
Low	12 (75%)	19 (43.2%)	3.95	1.10–14.19	0.041*	3.62	0.81–16.21	0.093
Medium/high	4 (25%)	25 (56.8%)						

Note: BMI: body mass index; *Significant p value < 0.05.

Table 4: Association between high-temperature exposure, BMI, physical activity, and sperm morphology.

Variable	Morphology		Bivariate			Multivariate		
	Abnormal	Normal	OR	CI 95%	p Value	OR	CI 95%	p Value
High-temperature exposure								
Medium/high	10 (31.3%)	1 (3.6%)	12.27	1.46–103.41	0.006*	9.25	0.99–86.53	0.051
Low	22 (68.8%)	27 (96.4%)						
BM								
Obesity	10 (31.3%)	6 (21.4%)	1.67	0.52–5.38	0.39	1.01	0.26–3.94	0.986
Nonobesity	22 (68.8%)	22 (78.6%)						
Physical activity								
Low	21 (65.6%)	10 (35.7%)	3.44	1.187–9.95	0.021*	2.56	0.835–7.88	0.100
Medium/high	11 (34.4%)	18 (64.3%)						

Note: BMI: body mass index; *Significant p value < 0.05.

was at 3.95 times risk of sperm motility (OR = 3.95; CI 95% = 1.10–14.18; $p = 0.041$), but in a multivariate analysis, low-physical activity (OR = 2.56 CI 95% = 0.835–7.88; $p = 0.100$), thus the lack of physical activity in this study was not the dominant variable affecting motility.

The results in Table 4 showed that exposure to high temperatures of medium/high intensity in the bivariate analysis (OR = 12.27; CI 95% = 1.46–103.41; $p = 0.006$) and multivariate analysis (OR = 9.25; CI 95% = 0.99–86.53; $p = 0.051$), thus heat exposure to nondominant variables affects sperm morphology. Obesity in the bivariate analysis (OR = 1.67; CI 95% = 0.52–5.38; $p = 0.391$) and multivariate analysis of obesity (OR = 1.01; 95%CI = 0.26–3.94; $p = 0.100$), meaning obesity had no statistically significant effect on sperm morphology with a $p > 0.05$ value. Low-physical activity is at 3.44 times the risk of abnormal sperm morphology (OR = 3.44; CI 95% = 1.19–9.95; $p = 0.100$), and a multivariate analysis of low-physical activity (OR = 2.56; CI 95% = 0.84–7.88; $p = 0.100$) which means lack of physical activity is not a risk factor for sperm morphology.

Table 5: Association of risk factor combinations with sperm concentration, motility, and morphology.

Risk	Total ($n = 60$)	Concentration			Motility			Morphology		
		Abnormal ($n = 15$)	Normal ($n = 45$)	p Value	Abnormal ($n = 16$)	Normal ($n = 44$)	p Value	Abnormal ($n = 32$)	Normal ($n = 28$)	p Value
High-temperature exposure, obesity, and physical activity$_{(low)}$	4	3 (20%)	1 (2.2%)	<0.001*	3 (18.8%)	1 (2.3%)	<0.001*	3 (9.4%)	1 (3.6%)	0.076
High-temperature exposure and physical activity$_{(low)}$	5	5 (33.3%)	0		4 (25%)	1 (2.3%)		5 (15.6%)	0	
High-temperature exposure and obesity	2	2 (13.3%)	0		0	2 (4.5%)		2 (6.3%)	0	
Obesity and physical activity$_{(low)}$	5	4 (26.7%)	1 (2.2%)		3 (18.8%)	2 (4.5%)		3 (9.4%)	2 (7.1%)	
Physical activity$_{(low)}$	17	1 (6.7%)	16 (35.6%)		2	15 (34.1%)		10 (31.3%)	7 (25%)	
Obesity	5	0	5 (11.1%)		3 (18.8%)	2 (4.5%)		2 (6.3%)	3 (10.7%)	
High-temperature exposure	0	0	0		0	0		0	0	
No risk	22	0	22 (48.9%)		1 (6.3%)	21 (47.7%)		7 (21.9%)	15 (53.6%)	

Note: Chi-sqaure test; *Significant p value < 0.05; normal-concentration ≥ 15 million/ml; motility PR + NP ≥ 40%; morphology ≥ 4%[12].

Based on Table 5, it was found that there is a statistically significant higher effect on sperm concentration and motility when previously mentioned risk factors were combined. A similar tendency was found, albeit non statistically significant, with sperm morphology ($p = 0.076$).

4. Discussion

The results of the study indicated that heat exposure had a negative impact on sperm quality. The duration of heat exposure was categorized into four groups, and the duration of exposure was measured in minutes per week. It was found that men who were exposed to high heat had lower sperm quality compared to those who were not exposed or exposed to lower levels of heat. In previous research by Ermiza [18], it was found that exposure to a temperature of 40°C for 45 min can decrease the production of sperm. Furthermore, exposure to high temperatures has also been shown to impact sperm quality negatively. Therefore, it can be concluded that exposure to high temperatures is a significant risk factor for sperm quality in humans [19, 20].

In addition, the study also found a correlation between obesity and diminished sperm quality. Although previous research has produced varied findings, several studies suggest that a higher BMI is associated with a decline in semen quality. In this context, men with obesity are three times as likely to have poor sperm quality compared to their normal-weight counterparts [21, 22]. Nonetheless, weight loss achieved through exercise, lifestyle modifications, or bariatric surgery can enhance serum testosterone levels and sperm count, suggesting improved male fertility [23].

On the other hand, this study reveals that lower physical activity levels can lead to a higher incidence of abnormal sperm concentration compared to medium/high physical activity. According to the WHO, respondents with high levels of physical activity displayed superior sperm quality compared to those with lower levels of physical activity [24]. Increased total physical activity, especially at moderate to vigorous intensity, has been associated with improved progressive and total sperm motility, suggesting that physical activity can positively influence male reproductive health, as reported by Sun et al. [25]. Therefore, men should maintain physical activity through regular and balanced exercise without overexerting themselves. However, it is essential to note that conflicting findings in the study by Ibañez-Perez et al. [12] did not find an association between physical activity and semen parameters.

5. Conclusion

Based on the statistical analysis, it can be concluded that high-temperature exposure, obesity, and physical activity are risk factors for sperm concentration. However, they do not significantly affect sperm morphology. On the other hand, obesity has been identified as a risk factor that significantly affects sperm motility.

Data Availability

The data supporting this study's findings are available from the corresponding author upon request.

Additional Points

Limitation. High-temperature exposure was arbitrarily determined with transportation methods, and does not take into account what happens in the other >9,500 min of the week, where exposure to heat could come from many other sources. Also it does not take into account climate when riding a bicycle or motorcycle in a cloudy/cold day. Other limitation is 71.3% of the sample were considered as "not exposed" to high temperatures. 53.3% were considered "normal weight," which means that the sample size for people that do not enter into those categories is relatively small. Also there is a low overall number of patients.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

We are grateful to Sebelas Maret University for its support of this study. Financial assistance has been provided through the Non-Anggaran Pendapatan dan Belanja Negara (Non-APBN) fund of Sebelas Maret University, grant number 254/UN27.22/PT.01.03/2022.

References

[1] World Health Organization, "WHO fact sheet on infertility," *Global Reproductive Health*, vol. 6, no. 1, Article ID e52, 2021.

[2] M. V Borght and C. Wyns, "Fertility and infertility: definition and epidemiology," *Clinical Biochemistry*, vol. 62, pp. 2–10, 2018.

[3] D. Durairajanayagam, "Lifestyle causes of male infertility," *Arab Journal of Urology*, vol. 16, no. 1, pp. 10–20, 2018.

[4] Y. Gong, H. Guo, Z. Zhang, H. Zhou, R. Zhao, and B. He, "Heat stress reduces sperm motility via activation of glycogen synthase kinase-3α and inhibition of mitochondrial protein import," *Frontiers in Physiology*, vol. 8, pp. 1–10, 2017.

[5] M. Rao, W. Xia, J. Yang et al., "Transient scrotal hyperthermia affects human sperm DNA integrity, sperm apoptosis, and sperm protein expression," *Andrology*, vol. 4, no. 6, pp. 1054–1063, 2016.

[6] N. Kumar and A. K. Singh, "Impact of environmental factors on human semen quality and male fertility: a narrative review," *Environmental Sciences Europe*, vol. 34, no. 1, 2022.

[7] K. Leisegang, R. Henkel, and A. Agarwal, "Obesity and metabolic syndrome associated with systemic inflammation and the impact on the male reproductive system," *American Journal of Reproductive Immunology*, vol. 82, no. 5, pp. 1–14, 2019.

[8] G. A. Ramaraju, S. Teppala, K. Prathigudupu et al., "Association between obesity and sperm quality," *Andrologia*, vol. 50, no. 3, Article ID e12888, 2018.

[9] P. Dudek, J. Kozakowski, and W. Zgliczyński, "The hypothalamic–pituitary–gonadal axis dysfunction in men practicing competitive sports," *Wiedza Medyczna*, vol. 2, no. 2, pp. 31–36, 2020.

[10] L. Moran, *The Role of Exercise and Physical Activity in Improving Fertility, Quality of Life and Emotional Well-Being*, The Fertility Society, 2021.

[11] A. M. Foucaut, C. Faure, C. Julia, S. Czernichow, R. Levy, and C. Dupont, "Sedentary behavior, physical inactivity and body composition in relation to idiopathic infertility among men and women," *PLoS One*, vol. 14, no. 4, Article ID e0210770, 2019.

[12] J. Ibañez-Perez, B. Santos-Zorrozua, E. Lopez-Lopez et al., "Impact of physical activity on semen quality among men from infertile couples," *European Journal of Obstetrics & Gynecology and Reproductive Biology*, vol. 237, pp. 170–174, 2019.

[13] K. M. Flegal, B. K. Kit, and B. I. Graubard, "Body mass index categories in observational studies of weight and risk of death," *American Journal of Epidemiology*, vol. 180, no. 3, pp. 288–296, 2014.

[14] W. L. Haskell, I. M. Lee, R. R. Pate et al., "Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association," *Medicine & Science in Sports & Exercise*, vol. 39, no. 8, pp. 1423–1434, 2007.

[15] IPAQ, "Guidelines for data processing and analysis of the international physical activity questionnaire (IPAQ)—short and long forms," 2005, http://www.ipaq.ki.se/scoring.pdf.

[16] WHO, *WHO Laboratory Manual for the Examination and Processing of Human Semen*, World Health Organization, 5th edition, 2010.

[17] World Health Organization, *WHO Laboratory Manual for the Examination and Processing of Human Semen*, World Health Organization, Geneva, 6th edition, 2021.

[18] E. Ermiza, "Pengaruh paparan suhu terhadap kualitas spermatozoa mencit jantan (mus,musculus) strain jepang," *Sainstis*, vol. 1, 2013.

[19] L. N. Garcia-Oliveros, R. P. de Arruda, L. Batissaco et al., "Heat stress effects on bovine sperm cells: a chronological approach to early findings," *International Journal of Biometeorology*, vol. 64, no. 8, pp. 1367–1378, 2020.

[20] A. M. Shahat, G. Rizzoto, and J. P. Kastelic, "Amelioration of heat stress-induced damage to testes and sperm quality," *Theriogenology*, vol. 158, pp. 84–96, 2020.

[21] R. Sharma, K. R. Biedenharn, J. M. Fedor, and A. Agarwal, "Lifestyle factors and reproductive health: taking control of your fertility," *Reproductive Biology and Endocrinology*, vol. 11, no. 1, pp. 1–15, 2013.

[22] K. K. Shukla, S. Chambial, S. Dwivedi, S. Misra, and P. Sharma, "Recent scenario of obesity and male fertility," *Andrology*, vol. 2, no. 6, pp. 809–818, 2014.

[23] Y. Liu and Z. Ding, "Obesity, a serious etiologic factor for male subfertility in modern society," *Reproduction*, vol. 154, no. 4, pp. R123–R131, 2017.

[24] World Health Organization (WHO), "Physical activity," 2022, March 3, 2023, https://www.who.int/news-room/fact-sheets/detail/physical-activity.

[25] B. Sun, C. Messerlian, Z.-H. Sun et al., "Physical activity and sedentary time in relation to semen quality in healthy men screened as potential sperm donors," *Human Reproduction*, vol. 34, no. 12, pp. 2330–2339, 2019.