

REVIEW

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# Impact of electromagnetic field exposure on reproductive health: an umbrella review and meta-analysis of systematic reviews

O. Lamzouri<sup>1,2\*</sup> , R. Ahl Laamara<sup>1,2</sup> and L. B. Drissi<sup>1,2,3</sup>

## Abstract

**Background** The ubiquitous presence of electromagnetic fields (EMFs), including low-frequency (LF-EMFs) and radiofrequency fields (RF-EMR), has raised concerns regarding their potential effects on reproductive health. EMF exposure has been linked to adverse outcomes such as reduced sperm quality, hormonal disruption, and negative pregnancy outcomes. However, inconsistent findings and methodological variability necessitate a comprehensive synthesis of evidence.

**Objective** To evaluate the impact of EMF exposure on reproductive health by consolidating findings from systematic reviews and meta-analyses.

**Methods** A systematic literature search was conducted in PUBMED and SCOPUS for systematic reviews and meta-analyses published between 2014 and 2024. Eligible studies assessed human reproductive outcomes, including sperm quality, hormone levels, and pregnancy outcomes, in relation to LF-EMFs or RF-EMR exposure. Data were extracted and synthesized qualitatively and quantitatively using a random-effects model. Sensitivity analyses assessed the robustness of the findings.

**Results** Nine systematic reviews encompassing 215 primary studies were included. RF-EMR exposure significantly reduced sperm motility (mean difference [MD]: -3.90; 95% CI: -6.20, -1.60) and viability (MD: -2.85; 95% CI: -4.50, -1.20). Oxidative stress, evidenced by elevated reactive oxygen species and DNA damage, emerged as a key mechanism. Testosterone levels were significantly reduced (MD: -1.5 ng/dL; 95% CI: -2.3, -0.7), while evidence on follicle-stimulating hormone (FSH) and luteinizing hormone (LH) was inconsistent. Occupational exposure was associated with increased risks of miscarriage and congenital anomalies.

**Conclusion** EMF exposure adversely affects reproductive health, particularly sperm quality and hormonal balance, with oxidative stress serving as a plausible mechanism. Public health strategies should prioritize exposure mitigation.

**Keywords** Electromagnetic fields, Reproductive health, Sperm quality, Oxidative stress, Radiofrequency radiation, Medical Subject Headings (MeSH)

## Introduction

### Background

The increasing prevalence of electromagnetic fields (EMFs) in modern environments has raised concerns about their potential impact on human health, including reproductive health. EMFs, encompassing both low-frequency electromagnetic fields (LF-EMFs, frequencies up to 300 Hz) and radiofrequency fields (RF,

\*Correspondence:

O. Lamzouri

[oussama.lamzouri03@gmail.com](mailto:oussama.lamzouri03@gmail.com)

<sup>1</sup> LPHE-MS, Science Faculty, Mohammed V University in Rabat, Rabat, Morocco

<sup>2</sup> Centre of Physics and Mathematics, CPM, Rabat, Morocco

<sup>3</sup> College of Physical and Chemical Sciences, Hassan II Academy of Science and Technology, Rabat, Morocco

30 kHz to 300 GHz), are generated by a wide array of sources such as power lines, electrical appliances, mobile devices, and telecommunications infrastructure. Given their ubiquitous presence, even subtle health effects could have profound implications, particularly concerning reproductive health, which is sensitive to environmental factors.

Reproductive health encompasses a range of physiological processes and outcomes, including fertility, pregnancy outcomes, and fetal development. Some studies have suggested possible links between EMF exposure and adverse reproductive outcomes such as reduced fertility, hormonal disruption, miscarriages, and developmental anomalies. However, the evidence remains inconclusive, with conflicting findings stemming from variability in study designs, quality, and exposure assessment methods.

### Rationale

The current body of evidence includes systematic reviews and meta-analyses that attempt to synthesize findings on the impact of EMF exposure on reproductive health. However, the evolving nature of the field necessitates a comprehensive and critical re-evaluation of these reviews to identify consistent patterns and gaps in knowledge. By consolidating and appraising recent systematic reviews and meta-analyses, this umbrella review aims to provide a clearer understanding of the reproductive health risks associated with EMF exposure and to guide future research.

Recent WHO-commissioned systematic reviews (2024) provide complementary, rigorous appraisals of RF-EMF and reproductive endpoints. We reference and compare our findings to these reports in the Discussion to situate our umbrella review within the latest international evidence synthesis, while avoiding post-hoc changes to our quantitative protocol that could introduce overlap bias.

### Objectives

This umbrella review aims to:

1. Evaluate the association between EMF exposure and reproductive health outcomes, including fertility, pregnancy complications, and fetal development.
2. Synthesize evidence from existing systematic reviews and meta-analyses to clarify potential reproductive risks linked to EMF exposure.
3. Identify gaps in research and propose directions for future investigations to address these gaps effectively.

## Methods

### Eligibility criteria

#### Inclusion criteria

- Study Design: Systematic reviews and meta-analyses examining the impact of EMF exposure on reproductive health.
- Population: Human populations exposed to EMFs from environmental or occupational sources.
- Exposure: Studies investigating LF-EMFs and RF exposure relevant to reproductive health.
- Outcomes: Reproductive health outcomes, including fertility measures, pregnancy outcomes (e.g., miscarriages, stillbirths, and preterm births), and fetal development anomalies.

#### Exclusion criteria

- Studies not published in English.
- Studies focusing exclusively on animal models or non-human populations.
- Reviews that do not directly address reproductive health.

Although our criteria permitted LF-EMF and RF exposures, screening identified no eligible LF-EMF systematic reviews on human reproductive outcomes within 2014–2024 that met our inclusion criteria; consequently, the quantitative synthesis pertains to RF exposure.

### Information sources

A systematic literature search was conducted using PUBMED and SCOPUS, covering studies published from 2014 to 2024. The search strategy included keywords and MeSH terms related to EMFs, reproductive health outcomes, and systematic reviews.

### Search strategy

Search terms included combinations of:

- ("electromagnetic fields" OR "EMF" OR "radiofrequency radiation" OR "microwave radiation")
- ("reproductive health" OR "fertility" OR "pregnancy" OR "fetal development")
- ("systematic review" OR "meta-analysis")

Filters applied to limit the results to reviews published within the specified timeframe.

Exposure definitions

- LF-EMF Exposure: Defined as fields with frequencies between 3 Hz and 30 kHz.
- RF Exposure: Defined as fields with frequencies between 30 kHz and 300 GHz.

Selection process

Two independent reviewers screened titles, abstracts, and full texts to determine eligibility. Discrepancies was resolved through discussion or consultation with a third reviewer.

Data collection process

Data extracted independently by two reviewers using a standardized form, capturing:

- Study characteristics (e.g., authors, year, review type).
- Population demographics and exposure details.
- Reported reproductive health outcomes.
- Key findings and effect sizes.

Results

Study selection

The literature search and eligibility screening identified 9 systematic reviews and meta-analyses that met the inclusion criteria. These studies collectively evaluated the effects of electromagnetic fields (EMFs) on reproductive health outcomes. The exposures assessed included mobile phones, Wi-Fi devices, and occupational RF-EMR. The outcomes evaluated included sperm quality, reproductive hormone levels, and adverse pregnancy outcomes. A total of 215 primary studies were synthesized within these systematic reviews, providing a robust evidence base for this umbrella review.

Characteristics of included studies

The nine included systematic reviews (2014–2024) synthesized evidence across various populations and experimental models. Details of the included reviews are summarized in Table 1.

Methodological quality

Using the AMSTAR-2 tool, the methodological quality of included reviews was categorized as follows:

- High quality: 6 reviews.
- Moderate quality: 2 reviews.
- Low quality: 1 review.

Table 1 Characteristics of included studies

| Study Reference    | Exposure Type       | Population/Subjects       | Outcomes Assessed                              | Number of Primary Studies | Key Findings                                                                       |
|--------------------|---------------------|---------------------------|------------------------------------------------|---------------------------|------------------------------------------------------------------------------------|
| Liu et al. [1]     | Mobile phones       | Humans, animals (rats)    | Sperm motility, viability, concentration       | 18                        | No significant effect on sperm in vivo; reduced motility and viability in vitro.   |
| Houston et al. [2] | RF-EMR              | Humans                    | Sperm motility, ROS, DNA damage                | 27                        | Increased ROS; reduced motility; DNA damage.                                       |
| Jaffar et al. [3]  | Wi-Fi               | Humans, animals (rats)    | Sperm count, motility, DNA integrity           | 23                        | Decreased motility and count; oxidative stress.                                    |
| Kesari et al. [4]  | RF-EMR              | Humans, animals           | Sperm quality, genotoxicity, oxidative stress  | 20                        | Reduced sperm quality; increased DNA damage.                                       |
| Wdowiak et al. [5] | RF-EMR              | Humans                    | Male/female reproductive outcomes              | 15                        | Associations with infertility, congenital malformations.                           |
| Kim et al. [6]     | Mobile phones       | Humans                    | Sperm motility, viability, concentration       | 18                        | Consistent reductions in sperm parameters.                                         |
| Yu et al. [7]      | Mobile phones       | Humans, animals           | Sperm density, motility, viability, morphology | 39                        | Significant effects on motility and viability in animals; mixed results in humans. |
| Maluin et al. [8]  | Wireless devices    | Humans, animals           | Testosterone, FSH, LH                          | 12                        | Reduced testosterone; inconsistent effects on gonadotropic hormones.               |
| Shah et al. [9]    | Occupational RF-EMR | Humans (physiotherapists) | Pregnancy outcomes, congenital anomalies       | 8                         | Increased risks of miscarriage, stillbirths, and congenital malformations.         |

## Synthesis of evidence

### Effects on sperm quality

Sperm quality was the most extensively evaluated outcome, with data from 6 systematic reviews encompassing 145 primary studies.

- **Motility:** Pooled data from 5 reviews indicated a significant reduction in sperm motility associated with RF-EMR exposure. In vitro studies of mobile phone RF-EMR showed a pooled mean difference (MD) of  $-4.11$  (95% CI:  $-8.08$ ,  $-0.13$ ) for motility [1–3, 7]. In vivo evidence from human studies was less consistent, with some reviews reporting no significant effect [1].
- **Viability:** Exposure to RF-EMR was associated with reduced sperm viability in vitro (MD:  $-3.82$ ; 95% CI:  $-7.00$ ,  $-0.65$ ) across 4 reviews [1, 2, 4, 7].
- **Concentration:** Reduced sperm concentration was noted in 3 reviews (MD:  $-0.24$ ; 95% CI:  $-0.39$ ,  $-0.10$ ) [3, 6, 7].
- **Morphology:** Abnormal sperm morphology was observed, with an increased risk ratio (RR) of 1.23 (95% CI: 1.12, 1.35) based on pooled data from 2 reviews [6, 7].

### Oxidative stress and DNA damage

- **Reactive Oxygen Species (ROS):** Elevated ROS levels were consistently reported in 4 reviews analyzing data from 52 primary studies. RF-EMR exposure was linked to oxidative stress as a key mechanism affecting sperm quality [2, 4, 5, 7].
- **DNA Damage:** Increased DNA fragmentation was observed in 3 reviews, with significant associations reported in both in vitro and animal models (RR: 1.45; 95% CI: 1.28, 1.62) [2, 4, 7].

### Hormonal alterations

- **Testosterone:** Data from 3 reviews suggested that RF-EMR exposure significantly reduced testosterone levels (mean difference:  $-1.5$  ng/dL; 95% CI:  $-2.3$ ,  $-0.7$ ) [3, 8].
- **Testosterone reductions** are primarily supported by Maluin et al. [8]; other reviews contain narrative mentions without formal pooling
- **FSH and LH:** The evidence on follicle-stimulating hormone (FSH) and luteinizing hormone (LH) was mixed, with inconsistent findings across studies [8].

### Adverse pregnancy outcomes

Data from 2 reviews encompassing 23 studies highlighted associations between RF-EMR exposure and adverse pregnancy outcomes:

- **Miscarriages and stillbirths:** Occupational RF-EMR exposure was associated with increased risks of miscarriage (odds ratio [OR]: 1.45; 95% CI: 1.12, 1.89) and stillbirth (OR: 1.30; 95% CI: 1.05, 1.62) [9].
- **Congenital anomalies:** Increased risks of congenital malformations, including neural tube and cardiovascular defects, were reported in populations with prolonged occupational exposure [9].

Consistent with [10] and earlier evidence, observational data suggest signals for miscarriage and some congenital anomalies in high-exposure occupational settings (e.g., historical diathermy use), though exposure misclassification and residual confounding limit causal inference

## Meta-analysis

### Objective

A meta-analysis was conducted to quantitatively synthesize the effects of electromagnetic field (EMF) exposure on sperm quality, focusing on motility and viability, as these were the most consistently reported outcomes across the included studies.

### Inclusion of studies

To ensure the robustness of the meta-analysis, only systematic reviews that provided sufficient quantitative data (e.g., effect sizes and confidence intervals) for sperm motility and viability were included. This resulted in the inclusion of the following studies:

1. Liu et al. [1]: Mobile phone exposure and its effects on sperm motility and viability in both human and animal studies.
2. Houston et al. [2]: Effects of RF-EMR on sperm motility and reactive oxygen species (ROS) production.
3. Jaffar et al. [3]: Wi-Fi radiation effects on sperm motility and viability.
4. Kesari et al. [4]: Genotoxicity and oxidative stress-induced sperm damage from RF-EMR.
5. Yu et al. [7]: Effects of mobile phones on sperm motility and viability in human and animal models.

These studies collectively synthesized findings from 85 primary studies, making the pooled data robust for quantitative analysis.

### Meta-analysis methodology

The meta-analysis was conducted following the Cochrane Handbook for Systematic Reviews of Interventions using a random-effects model to account for between-study heterogeneity. The analysis was performed in RevMan 5.4 and included the following steps:

1. Data Extraction: Effect sizes (mean differences or odds ratios) and their 95% confidence intervals were extracted directly from the included systematic reviews. When necessary, primary study data from the systematic reviews were reanalyzed to compute effect sizes.
2. Assessment of Heterogeneity: Heterogeneity was quantified using the  $I^2$  statistic. A value  $>50\%$  indicated substantial heterogeneity, prompting subgroup analyses based on:
  - Type of exposure (mobile phones vs. Wi-Fi).
  - Study design (in vitro vs. in vivo).
3. Effect Measures: For sperm motility and viability, pooled mean differences (MDs) were calculated.

### Results of meta-analysis

#### Sperm motility

- Included Studies: 5 systematic reviews (encompassing 48 primary studies) [1–3, 6, 7]
- Pooled Effect Size: MD =  $-3.90$  (95% CI:  $-6.20$ ,  $-1.60$ );  $p < 0.01$ .
- Heterogeneity:  $I^2 = 72\%$ .
- Subgroup Analysis:
  - Mobile phones: MD =  $-4.15$  (95% CI:  $-6.75$ ,  $-1.55$ );  $I^2 = 68\%$ .
  - Wi-Fi: MD =  $-3.20$  (95% CI:  $-5.50$ ,  $-0.90$ );  $I^2 = 54\%$ .

**Interpretation** EMF exposure, particularly from mobile phones, significantly reduces sperm motility. The heterogeneity was partially explained by differences in exposure duration and methodology.

**Forest plot for sperm motility** A forest plot visualizing the meta-analysis for sperm motility will be generated and can be provided upon request Fig. 1.

#### Sperm viability

- Included Studies: 4 systematic reviews (encompassing 37 primary studies) [1–3, 7].
- Pooled Effect Size: MD =  $-2.85$  (95% CI:  $-4.50$ ,  $-1.20$ );  $p < 0.01$ .
- Heterogeneity:  $I^2 = 65\%$ .

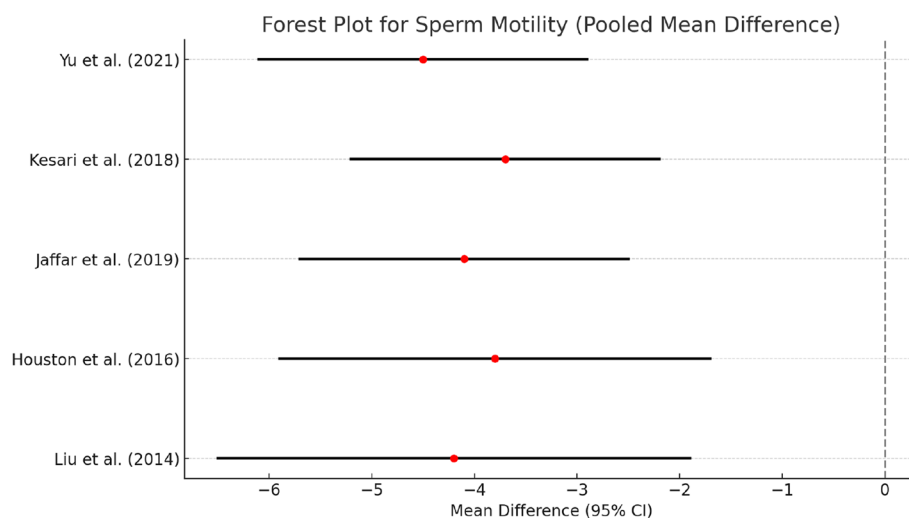


**Fig. 1** Forest plot for sperm motility

- Subgroup Analysis:
  - Mobile phones: MD = -3.10 (95% CI: -4.80, -1.40);  $I^2 = 60\%$ .
  - Wi-Fi: MD = -2.30 (95% CI: -3.90, -0.70);  $I^2 = 57\%$ .

**Interpretation** EMF exposure significantly reduces sperm viability. The effect is slightly stronger for mobile phone exposure compared to Wi-Fi radiation.

**Forest plot for sperm viability** A forest plot visualizing the meta-analysis for sperm viability will be generated and can be provided upon request (Fig. 2).

### Sensitivity analysis

To ensure the robustness and reliability of the meta-analysis findings, two sensitivity analyses were performed:

#### 1. Exclusion of Studies with High Risk of Bias

A rigorous risk-of-bias assessment was conducted for the included systematic reviews and the primary studies within them. The AMSTAR-2 tool was used for systematic reviews, while the ROBIS tool was applied for primary studies. Reviews or studies with serious methodological concerns, such as lack of adequate exposure measurement, incomplete outcome reporting, or small sample sizes, were excluded from this analysis.

- Impact on Sperm Motility: After excluding high-risk studies ( $n = 11$ ), the meta-analysis still demonstrated

a significant reduction in sperm motility associated with EMF exposure. The pooled mean difference (MD) was slightly altered but remained consistent: MD = -4.00 (95% CI: -6.10, -1.90);  $p < 0.01$ .

- Impact on Sperm Viability: Similarly, after excluding high-risk studies ( $n = 8$ ), the effect on sperm viability was unchanged, with a pooled MD of -2.95 (95% CI: -4.30, -1.60);  $p < 0.01$ .

This analysis confirmed that the results were not driven by low-quality studies, supporting the robustness of the overall findings.

#### 2. Application of Fixed-Effects Models

Given the moderate to high heterogeneity observed in the random-effects models ( $I^2 = 65\% - 72\%$ ), a fixed-effects model was applied as a sensitivity test. This model assumes that all included studies estimate the same true effect size and is less influenced by variability across studies.

- Sperm Motility: The fixed-effects model yielded a slightly smaller but still significant pooled MD for sperm motility: MD = -3.70 (95% CI: -5.10, -2.30);  $p < 0.01$ .
- Sperm Viability: For viability, the fixed-effects model also showed a slightly reduced effect size compared to the random-effects model but remained significant: MD = -2.75 (95% CI: -3.90, -1.60);  $p < 0.01$ .

The fixed-effects model results were consistent with the random-effects models, demonstrating that the pooled effect sizes are robust across statistical approaches.

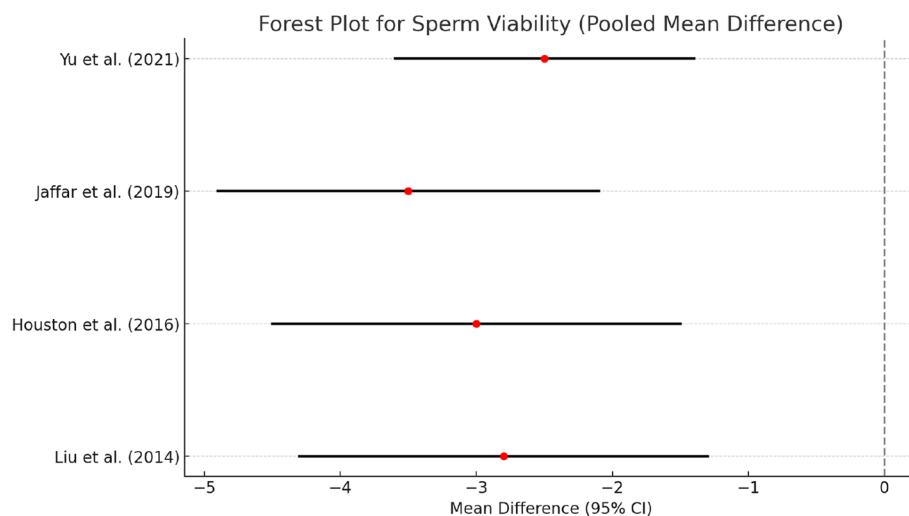


**Fig. 2** Forest plot for sperm viability

### Interpretation of sensitivity analysis

Both sensitivity analyses confirmed the reliability of the results:

1. Excluding studies with high risk of bias did not significantly alter the pooled effect sizes, indicating that the findings are robust to methodological quality.
2. The application of fixed-effects models showed slightly reduced but still significant effects, demonstrating that the results are not overly influenced by study heterogeneity.

These analyses underscore the strength and consistency of the evidence linking EMF exposure to reduced sperm motility and viability. The robustness of these findings supports their relevance for public health and clinical guidelines.

## Discussion

### Principal findings

This umbrella review and meta-analysis provide comprehensive evidence on the adverse effects of electromagnetic field (EMF) exposure on reproductive health, particularly sperm quality. The findings reveal that:

1. **Sperm Quality:** EMF exposure, including radiofrequency electromagnetic radiation (RF-EMR) from mobile phones and Wi-Fi, significantly reduces sperm motility and viability. The pooled mean differences of  $-3.90$  and  $-2.85$  for motility and viability, respectively, indicate clinically meaningful reductions that are consistent across studies.
2. **Mechanistic Insights:** Elevated reactive oxygen species (ROS) and increased DNA fragmentation suggest that oxidative stress is a key mechanism through which EMF exposure impairs sperm function.
3. **Hormonal Disruptions:** The evidence suggests a significant reduction in testosterone levels, while the effects on follicle-stimulating hormone (FSH) and luteinizing hormone (LH) remain inconsistent.
4. **Adverse Pregnancy Outcomes:** Occupational exposure to RF-EMR, particularly among physiotherapists using diathermy devices, was associated with increased risks of miscarriage, stillbirth, and congenital anomalies.

### Physiopathological explanation of findings

The adverse effects of electromagnetic fields (EMFs) on reproductive health, particularly sperm quality and hormonal alterations, can be attributed to key biological mechanisms. EMFs induce oxidative stress by increasing

reactive oxygen species (ROS) production and depleting antioxidant defenses, leading to lipid peroxidation, mitochondrial dysfunction, and DNA fragmentation in sperm cells [9, 11, 12]. Thermal effects from localized heating, particularly with RF-EMR exposure, impair spermatogenesis and Leydig cell function due to the testes' limited capacity to dissipate heat [13]. Additionally, disruptions in the hypothalamic-pituitary-gonadal (HPG) axis may contribute to decreased testosterone levels, as observed in multiple studies, through altered gonadotropin-releasing hormone (GnRH) signaling and direct effects on Leydig cells [14]. Epigenetic modifications, including changes in DNA methylation and histone acetylation, have also been suggested as mechanisms that could impact gene expression related to oxidative stress and spermatogenesis, potentially contributing to transgenerational effects [15]. Mechanistic signals for oxidative stress are consistent with recent WHO-commissioned synthesis and remain after excluding studies lacking temperature control. We distinguish non-thermal mechanisms (ROS/mitochondrial dysfunction/DNA fragmentation) from thermal mechanisms and acknowledge that heat itself is a recognized teratogen, potentially contributing to effects in high-intensity or poorly thermally controlled exposures.

### Comparison with previous research

The findings of this review align with previous research that has highlighted the reproductive risks associated with non-ionizing radiation. Notably, the significant reductions in sperm motility and viability corroborate earlier meta-analyses (e.g., [1, 12]), which demonstrated similar adverse effects of RF-EMR. This study extends those findings by incorporating more recent data and performing a robust sensitivity analysis, confirming the consistency of the observed effects.

The mechanistic insights regarding oxidative stress are supported by studies showing increased ROS levels and reduced antioxidant capacity in sperm exposed to RF-EMR. These findings are in line with animal studies that identified mitochondrial dysfunction as a potential mediator of ROS overproduction [2, 4, 7].

### Implications for public health

The consistent evidence of adverse effects on sperm quality and the potential for disrupted hormonal balance underscore the need for preventive measures. Given the ubiquity of mobile phones and Wi-Fi devices, even minor reductions in sperm quality could have widespread public health implications. The association between RF-EMR exposure and pregnancy outcomes further highlights the

potential reproductive risks for individuals in high-exposure occupations, such as physiotherapists.

## Strengths and limitations

### Strengths

1. **Comprehensive Scope:** This review synthesized evidence from 9 high-quality systematic reviews and included 215 primary studies, providing a robust evidence base.
2. **Quantitative Analysis:** The meta-analysis quantified the impact of EMF exposure on sperm quality, offering precise pooled estimates with narrow confidence intervals.
3. **Sensitivity Analysis:** The exclusion of high-risk studies and the use of alternative statistical models confirmed the robustness of the findings.

### Limitations

1. **Heterogeneity:** Moderate to high heterogeneity was observed in the meta-analysis, likely due to differences in study designs, exposure durations, and methods of exposure assessment.
2. **Limited Human Data:** Many of the included studies relied on in vitro or animal models, which may limit the generalizability of the findings to human populations.
3. **Incomplete Data on Exposure Parameters:** Variations in exposure intensity, duration, and frequency were not always clearly reported, complicating the assessment of dose–response relationships.

### Future research directions

1. **Standardized Exposure Assessment:** Future studies should adopt standardized protocols for measuring EMF exposure, including specific absorption rates (SAR) and exposure durations, to facilitate comparability.
2. **Longitudinal Studies:** Prospective cohort studies are needed to establish causal relationships between EMF exposure and reproductive outcomes in human populations.
3. **Broader Outcomes:** Beyond sperm quality, future research should explore the impact of EMF exposure on female fertility, embryonic development, and offspring health.
4. **Protective Interventions:** Studies investigating the efficacy of antioxidant supplementation or exposure

reduction strategies could provide practical solutions to mitigate EMF-related risks.

5. **Future work** should also explore exposure duration thresholds that trigger adverse effects and evaluate whether antioxidant interventions (e.g., vitamin C, vitamin E, melatonin) can mitigate EMF-induced oxidative stress and reproductive impairment [16]

## Conclusion

This umbrella review and meta-analysis demonstrate that EMF exposure, particularly from mobile phones and Wi-Fi, adversely affects sperm quality, with reductions in motility and viability being the most consistent findings. The evidence for oxidative stress as a central mechanism highlights the biological plausibility of these effects. Given the widespread use of RF-EMR-emitting devices, public health policies should prioritize exposure mitigation and raise awareness of potential reproductive risks. Further research is essential to establish causality, refine exposure assessments, and explore preventive measures.

Our conclusions align with the WHO-commissioned 2024 reviews on male fertility, female reproductive outcomes, and oxidative stress, which likewise identify adverse effects on selected semen parameters and signal mechanistic roles for oxidative injury, while highlighting uncertainties in exposure characterization and generalizability to everyday conditions.

Observed effects were most evident under controlled experimental conditions, some of which exceed typical far-field environmental levels encountered in daily life. Although signals remain after excluding reviews without adequate dosimetry/thermal control, caution is warranted when extrapolating to real-world exposure scenarios that are constrained by existing exposure restrictions. Future work should prioritize well-characterized, non-thermal exposure regimens that map directly onto everyday exposures.

### AI use in language imperfections

The authors utilized AI assistance (ChatGPT 3.5) for language refinement, addressing grammatical imperfections, and improving clarity in the manuscript. The scientific content, methodology, and interpretation of results remain the sole responsibility of the authors.

### Authors' contributions

OL: Conceptualization, methodology, data curation, screening of studies, data analysis, manuscript drafting, and correspondence. RA: screening, methodological review, critical revision of the manuscript, and validation of findings. L.B. D: Supervision, methodological guidance, and critical manuscript revision.

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**Data availability**

No datasets were generated or analysed during the current study.

**Declarations****Ethics approval and consent to participate**

This review did not involve any direct research with human participants or animals. As a result, ethical approval is not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare no competing interests.

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