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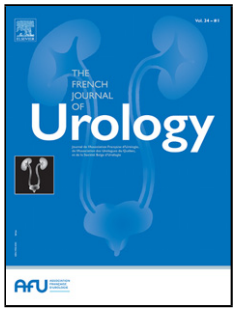

Impact of non ionising radiation of male fertility

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Impact des rayonnements non ionisants sur la fertilité masculine

Impact of non ionising radiation of male fertility

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Impact of non-ionizing radiation on male fertility

Summary

Exposure to non-ionizing radiation has become inevitable because people cannot escape sources of electromagnetic fields, such as Wi-Fi or cell phones.

Among the mechanisms mentioned, the energy emitted by this non-ionizing radiation could cause heating which would have harmful effects on the quality of the sperm.

The objective of our study was to carry out a systematic review of the literature concerning the impact of exposure to non-ionizing radiation from mobile phones (or other sources) on sperm parameters.

We selected 12 studies: the majority of in vivo studies in humans and in vitro studies in animals report a significant impact on sperm count, mobility and vitality.

Mobility and vitality seem to be the parameters most regularly impacted by exposure to non-ionizing radiation.

Additional studies are necessary to complete this study in order to deepen knowledge with new generations of mobile phones which can raise health concerns.

Keywords: non ionizing radiation, radiofrequency, electromagnetic radiation, cellular phone, mobile phone, cell phone, microwave rays and infrared rays then male fertility, semen, semen parameters, spermatozoa.

Impact des rayonnements non ionisants sur la fertilité masculine

Résumé

L'exposition aux rayonnements non ionisants est devenue inévitable car les personnes ne peuvent pas échapper aux sources de champs électromagnétiques, telles que le Wi-Fi, ou encore les téléphones portables.

Parmi les mécanismes évoqués, l'énergie émise par ces rayonnements non ionisants pourrait provoquer un échauffement ce qui engendrerait des effets néfastes sur la qualité du sperme.

L'objectif de notre étude était de réaliser une revue systématique de la littérature concernant l'impact de l'exposition à ces radiations non ionisantes provenant des téléphones portables (ou autres sources) sur les paramètres spermatiques.

Nous avons sélectionné 12 études : la majorité des études in vivo chez l'homme et in vitro chez l'animal rapportent un impact significatif sur la numération, la mobilité et la vitalité des spermatozoïdes.

La mobilité et la vitalité semblent les paramètres les plus régulièrement impactés par l'exposition aux radiations non ionisantes.

Des études complémentaires sont nécessaires pour compléter cette étude afin d'approfondir les connaissances avec les nouvelles générations de téléphones portables qui peuvent susciter des inquiétudes sur la santé.

Mots-clés : rayonnements non ionisants, radiofréquence, rayonnement électromagnétique, téléphone portable, rayons micro-ondes et infra-rouge puis fertilité masculine, sperme, paramètres du sperme et spermatozoïdes.

INTRODUCTION

With increasing technological development, exposure to non-ionising radiation has become unavoidable, as people cannot escape sources of electromagnetic fields such as Wi-Fi, electrical installations, microwave ovens, radio and mobile phones. This radiation can be associated with increased health problems for users. On a daily basis, health professionals are frequently asked about these issues by patients and their families.

To date, in vivo and in vitro studies have revealed that exposure to non-ionising radiation has harmful effects on female fertility: a reduction in the number of ovarian follicles, morphological changes in oocytes and histological changes in the ovaries and uterus (1). Non-ionising radiation also increases the load of free radicals in the uterus and ovaries, leading to inhibition of cell growth and disruption of DNA (1). As a result, non-ionising radiation can cause both alterations to germ cells and their environment, which can affect female reproductive parameters and lead to infertility.

Around 14% of couples in industrialised countries have difficulty conceiving, with responsibility shared between the man and the woman (2).

Mobile phones are widely used in industrialised countries, including by men of childbearing age. The radiofrequency electromagnetic fields emitted by mobile phones, between 800 and 2200 MHz, can be absorbed by the human body (3). Numerous concerns have been expressed about the potential health effects of exposure to this radiation (3). Among the mechanisms mentioned, the energy emitted by these non-ionising rays could cause heating, which could have harmful effects on the heart, the brain (brain tumours (4), Alzheimer's disease (5), (6),

the endocrine system and the reproductive function, in particular by altering the quality of sperm (4). Other non-thermal interactions could also come into play, such as the production of reactive oxygen species, which are particularly harmful to DNA (5).

The aim of our study was to carry out a systematic review of the literature on the impact of exposure to non-ionising radiation from mobile phones (or other sources) on sperm parameters.

MATERIALS AND METHODS

Search strategy

We used the PRISMA 2020 method for systematic reviews (9). We searched four databases: PUBMED/MEDLINE, GOOGLE SCHOLAR, WEB OF SCIENCE, and EMBASE.

We focused our research on the impact of non-ionising radiation on the following sperm parameters: Count, Concentration, Mobility, Vitality, Morphology and Reactive Oxygen Species Production.

The search equations included the following Mesh Terms, Mesh Major Topic and Mesh Subheadings: "non ionizing radiation", "radiofrequency", "electromagnetic radiation", "cellular phone", "mobile phone", "cell phonemicrowave rays" and "infrared rays" on the one hand, and "male fertility", "semen", "semen parameters", "spermatozoa" on the other, connected by "and".

Selection of studies

The selected studies were designed to analyse the impact of non-ionising radiation on sperm parameters.

We included publications that were original studies carried out in humans or animals, available in full text, published in French or English and having a control group. There was no restriction on the date of publication.

We excluded publications that were meta-analyses, case reports, literature reviews or book chapters.

The levels of evidence were established for each article included in our study according to the recommendations of the Haute Autorité de Santé (HAS) 2013 (6): the level of evidence of a study characterises the study's ability to answer the question posed. The ability of a study to answer the question posed is judged on the correspondence of the study to the framework of the work (question, population, judgment criteria) and on the following characteristics:

- The appropriateness of the study protocol to the question posed
- Whether or not the study was subject to significant bias
- The suitability of the statistical analysis for the objectives of the study
- The power of the study, and in particular the size of the sample

The levels of evidence according to the HAS are presented in table 1.

Data collected

For each study selected, the reference, authors, publication date, study design, level of evidence, semen collection method, study population, size of the study population, inclusion and exclusion criteria, type of exposure (type of non-ionising radiation), confounding factors, statistical results (odds ratio OR, relative risk RR, and 95% CI confidence intervals), and the limitations and strengths of the study considered were collected in a general table.

RESULTS

Study selection process

Figure 1 represents the flowchart of study identification and selection.

The included studies were published from 1999 to 2019.

The 12 studies selected analysed a total of 1172 patients and 136 animals (rats and ganders). Eleven studies were conducted with exposure to electromagnetic radiation from mobile phones and one with exposure to monochromatic light sources.

Six studies were conducted in humans (table 2) and 6 in animals (table 3).

In humans, 3 studies examined sperm parameters after in vivo exposure, and 3 others after in vitro exposure. Of the 6 studies, 5 were conducted with mobile phones switched on and one with electromagnetic radiation at the same frequency as mobile phones. The studies selected were observational, prospective and case-control, which correspond to a low level of scientific evidence according to the HAS.

In animals, the 6 studies examined sperm parameters in vivo. Five studies reported exposure to switched-on mobile phone radiation ranging from 915 Hertz to 1.8 GHertz.

Impact of exposure on sperm parameters

-Count and Concentration:

Two out of 3 in vivo studies in humans reported significant results:

- The study by Agarwal et al (7) showed a significant decrease in users of 2 to 4 hours or more than 4 hours per day per day, compared with no use or less use;
- The study by Sajeda et al (4) reported a significant decrease in sperm count as a function of the duration in years of use of a mobile phone in users for 4 to 6 years compared with the group exposed for 1 to 3 years.

One of 6 animal studies reported significant results:

- The study by Gautam et al (8) showed a significant reduction in epididymal sperm counts in rats exposed for 2 hours a day compared with the unexposed group.

-Mobility

Four out of 4 in vivo and in vitro studies in humans reported significant results:

-The study by Agarwal et al (7) showed a significant decrease in sperm motility in mobile phone users for 2 to 4 hours of use per day and more than 4 hours of use per day compared with no use or less use;

-The study by Sajeda et al (4) reported a significant decrease in sperm motility as a function of the duration of mobile phone use in users for 4 to 6 years compared with the group exposed for 1 to 3 years;

-The study by Veerachari et al (9) showed a significant decrease in motility for an acute in vitro exposure of 60 min compared with the unexposed control group;

-The study by Zalata et al (10) showed a significant reduction in all groups exposed in vitro for 60 minutes compared with the unexposed group;

-The study by De Luliis et al (5) showed a significant reduction for an in vitro exposure of 16 hours compared with the control group.

Four out of four animal studies reported significant results:

-The study by Mailankot et al (11) showed a significant reduction for exposure of one hour per day for 28 days compared with the control group;

-The study by Ghanbari et al (12) showed a significant reduction for exposure of 14 days or more compared with no use, or less use;

-The study by Chang et al (13) showed a significant reduction for exposure to 3 types of monochromatic light sources;

-The study by Yan et al (14) showed a significant reduction for a duration of exposure of 3 hours per day for 18 weeks compared with the unexposed group.

-Vitality

The 3 human studies that have examined vitality have reported significant results:

-The study by Agarwal et al (6) showed a significant reduction for use of 2 to 4 hours per day compared with no use, or less use;

-The study by Veerachari et al (9) showed a significant difference for exposure of 60 minutes compared with the unexposed control group;

The study by De Luliis et al (5) showed a significant reduction for a 16-hour exposure compared with the control group.

The 3 animal studies that examined vitality in animals reported significant results:

-The study by Gautam et al (8) showed a significant reduction for exposure of 2 hours a day for 45 days compared with the unexposed group;

-The study by Ghanbari et al (12) showed a significant reduction in all groups for a duration of use of 14 days or more;

-The study by Chang et al (13) showed a significant reduction in all monochromatic light exposure groups.

-Morphology

Only one study out of 5 in humans has shown significant results:

The study by Agarwal et al (7) showed a significant reduction in typical forms in the groups using mobile phones for more than 2 hours a day compared with the non-use group.

Only one of the 5 animal studies showed significant results:

-The study by Chang et al (13) showed a significant reduction in typical forms in the 3 groups using blue, white and red monochromatic light.

-DNA fragmentation

The only study to analyse fragmentation reported significant results:

-The study by Rago et al (15) showed a significant increase in sperm DNA fragmentation in the group using more than 4 hours per day and in the group where the mobile phone was located in the trouser pocket.

DISCUSSION

Most of the studies selected in our systematic review reported significant decreases in sperm parameters after exposure to non-ionising radiation: 5 studies out of 6 in humans and 5 studies out of 6 in animals showed significant results for motility. Two out of 3 human studies and 1 out of 6 animal studies showed significant results for sperm count and sperm concentration. All 3 human studies and all 3 animal studies investigating vitality showed significant results. One in 5 human studies and 1 in 5 animal studies showed significant results for sperm morphology.

Mobility and vitality therefore appear to be the parameters most regularly impacted by exposure to non-ionising radiation and in humans, the majority of in vivo studies report significant results for sperm count, mobility and vitality.

The consistency of the results between in vivo and in vitro studies adds confidence to the findings.

The possibility of confounding variables influencing the results cannot be ruled out. Indeed, of the 3 in vivo studies in humans, only one presented a multivariate statistical analysis, taking into account only the age of the man. In addition, measurement bias cannot be ruled out in 2 observational studies in humans (15)(7): exposure to ionising radiation via the use of mobile phones was obtained by patient self-report (and not measured by the experimenter).

The main mechanisms of action evoked by non-ionising radiation concern thermal and non-thermal effects on biological tissues.

Non-thermal effects would increase the production of reactive oxygen species, which could lead to DNA damage, more specifically DNA strand breaks (14). A high rate of sperm DNA fragmentation could lead to an increased risk of aneuploid gametes (16).

The thermal effects of using a mobile phone can be generated both by the heat of the handset and by the emission of electromagnetic waves. However, the impact of the thermal effects of electromagnetic radiation is negligible (7), (17), (18). These thermal effects could raise testicular temperature since mobile phones are often kept in trouser pockets, close to the reproductive organs. This hyperthermia could alter spermatogenesis (11): in infertile men, it has been shown that the higher the scrotal temperature, the more sperm parameters were altered (19). Furthermore, we know that a 2°C increase in scrotal temperature for 16 hours a day in animals (rams) is associated with a reduction in the rate of embryonic implantation (20). This negative effect on embryonic development can be observed in vitro through a delay in the first embryonic cleavage (21). The idea that an increase in testicular temperature leads to an alteration in spermatogenesis is widely accepted (22): in men, an increase in the time taken to conceive has been observed in men exposed to testicular hyperthermia (23), fever can lead to an alteration in sperm parameters and men with varicocele have significantly higher scrotal temperatures than normozoospermic men (24).

On the basis of risk assessments published to date at international level, both by the World Health Organisation (WHO) and the International Commission on Non-Ionising Radiation Protection (ICNIRP), on 12 July 1999 the Council of the European Union published a recommendation on limiting public exposure to all electromagnetic fields (from 0 Hz to 300 GHz) (25).

This recommendation defines exposure limit values, known as "basic restrictions", which are fifty times lower than the exposure levels capable of causing significant heating of tissues, the

only proven effect of prolonged exposure to electromagnetic radiation in the frequency range in question.

The SAR (Specific Absorption Rate) is defined by the ANFR (Agence Nationale des Fréquences) to quantify the energy transmitted by electromagnetic waves and absorbed by the human body. The "head" SAR reflects the use of the mobile phone under voice conditions. The "trunk" SAR reflects the position of the mobile phone close to the trunk, such as in a jacket or trouser pocket. The limit values for these SARs, which must not be exceeded, are defined by European recommendation 1999/519/EC for the "head" and "trunk" SARs: 2 W/Kg (26). This SAR makes it possible to quantify the effect of electromagnetic waves for all waves between 100 KHz and 10 GHz, which include those mentioned in our studies.

The results of the articles selected for our review show a harmful effect in humans of the duration of exposure to non-ionising radiation on sperm quality (15)(7), as has been demonstrated in rats (11)(27).

Exposure to non-ionising radiation could be part of a cumulative effect with modern environmental exposures such as Wi-Fi from laptops, which could also alter sperm quality (28).

A better understanding of this multifactorial influence could improve the support and treatment of infertile couples.

CONCLUSION

The studies selected for this study suggest significant associations between exposure to electromagnetic radiation and sperm quality, mainly sperm vitality and motility.

Among the mechanisms suggested, thermal effects appear to be more deleterious to sperm parameters than non-thermal effects.

Further research is needed to quantify these effects more precisely and also to assess the clinical significance of the risk for both hypofertile men and the general population.

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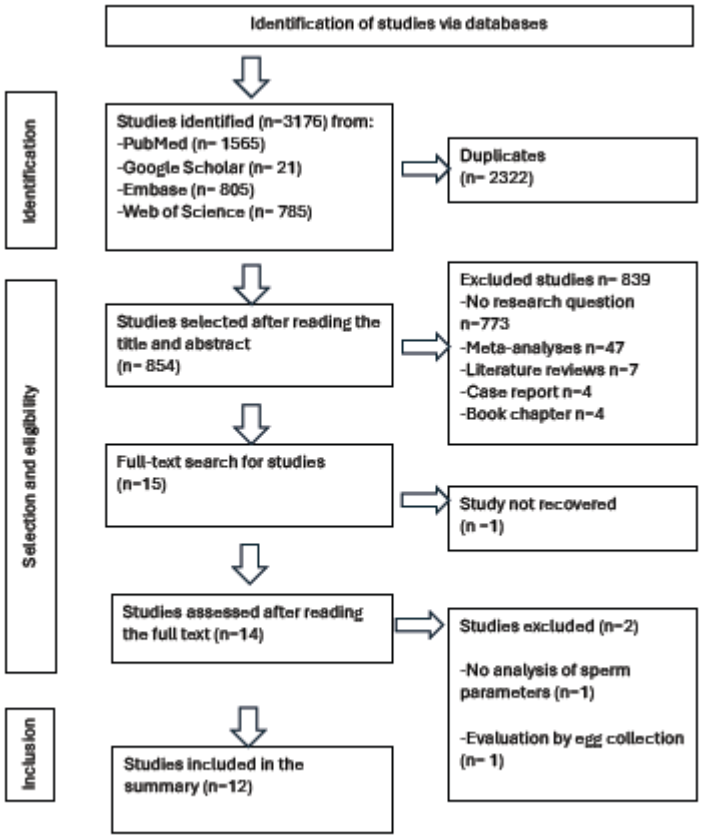
Figure 1

Flowchart of study identification and selection.

Figure 1 represents the flowchart of study identification and selection



LEGEND

Table 1

Level of evidence and grading of good practice recommendations, HAS April 2013 (10)

Table 2

Results in humans

Table 3

Results in animals

TABLES

Table 1

Level of Evidence	Grade of Recommendation
Level I: Large randomized trials with clear-cut results (and low risk of error)	A
Level II: Small randomized trials with uncertain results (and moderate to high risk of error)	B
Level III: Nonrandomized, contemporaneous controls	
Level IV: Nonrandomized, historical controls	C
Level V: No controls, case-series only	

Table 2

Results in humans							
Title, 1st author and year	Type of study	Age	Nature of exposure	Duration of exposure	Comparison / groups	Judging criteria	Endpoints Results (95% CI) and Type of analysis (univariate or multivariate)
1-The Semen quality of the mobile phone users R. Rago 2013 (14)	Observational study In vivo	18 to 35	Mobile phone on	Chronic	63 patients divided into 4 groups : -Group A: n=10 no use -Group B: n=16 < 2h / day	Sperm parameters : -volume -total number -morphology (% normal shape) -progressive mobility	Univariate analysis ANOVA followed by Ducan test All results are non-significant except for : DNA fragmentation (%) -group A: (3 +/- 1.2) NS

					-groupe C: n=17 2 à 4 h / day -groupe D: n=20 > 4h / day -> itself subdivided into trouser pockets (12) and shirt pockets (8)		-group B: (3.2 +/- 1.6) NS -group C: (3.1 +/- 2.2) NS -group D versus other groups: (6.6 +/- 2.2) p<0.05 ->trouser pocket versus shirt pocket: (6.7+/- 1.8) p<0.05 ->shirt pocket: (5,1 +/- 1,3) NS

2-Effect of cell phone usage on semen analysis in men attending infertility clinic: an observational study Ashok Agarwal 2008 (6)	Observational study In vivo	31,81 +/- 6,12 years (Mean +/- standard deviation)	Mobile phone switched on and talking	Chronic	361 patients divided into 4 groups : -Group A: n=40 no use -Group B: n=107 < 2h / day -group C: n=100 2 to 4 h / day -group D: n=114 > 4h / day 2 groups for multivariate analysis :	8 sperm parameters : -Volume -Liquefaction time -pH -Viscosity -Concentration -Mobility -Vitality -Morphology	Multivariate analysis Confidence intervals for differences between mobile phone use groups assessing the 8 sperm parameters Volume (ml) NS p>0.05 Liquefaction time (min) NS p>0.05 pH -Group A versus B: -0.115 to 0.105 NS p>0.05 -Group A versus C: -0.209 to 0.014 nm p>0.05

					-<4h/day (n=247) ->4h/day (n=114) >4h/day		-Group A versus D: -0.223 to -0.004 nm p>0.05 -Group B versus C : -0.175 to -0.009 p<0.05 -Group B versus D : -0.189 to -0.02 p<0.05 -Group C versus D : -0.098 to -0.065 NS p>0.05 Viscosity NS p>0.05 Concentration (10*6 / ml) -Group A versus B: -1.67 to 4.4 NS p>0.05 -Group A versus C :

							1.29 to 7.49 p<0.05 -Group A versus D : 4.05 to 10.03 p<0.05 -Group B versus C : -0.85 to 2.57 NS p>0.05 -Group B versus D : 0.6 to 3.81 p<0.05 -Group C versus D : -1.35 to 1.97 NS p>0.05 Mobility (%) -Group A versus B: -6.16 to 45.83 NS p>0.05 -Group A versus C: 12.86 to 65.11 NS p>0.05 -Group A versus D:

							22.71 to 74.49 NS p>0.5 -Group B versus C : 11.04 to 56.09 p<0.5 -Group B versus D: 22.21 to 66.52 nm p>0.5 -Group C versus D : 6.65 to 51.36 p<0.05 Vitality (%) -Group A versus B: -5.55 to 48.84 NS p>0.05 -Group A versus C : 14.04 to 68.70 p<0.05 -Group A versus D : 24.42 to 78.59 NS p>0.05 -Group B versus C:

							11.69 to 58.82 nm p>0.05 -Group B versus D: 23.55 to 69.92 nm p>0.05 -Group C versus D : 7.29 to 54.07 p<0.05 Morphology (% normal) -Group A versus B: 0.12 to 1.11 p<0.05 -Group A versus C : 2.65 to 3.66 NS p>0.05 -Group A versus D : 4.14 to 5.12 NS p>0.05 -Group B versus C : 0.7 to 1.26 p<0,05 -Group B versus D :

							1.60 to 2.12 p<0.05 -Group C versus D : -0.12 to 0.41 NS p>0.05 Multivariate analysis MANCOVA Adjustment for patient age : Significant differences p<0.05 for: PH -group B versus C -group B versus D Sperm count (10*6/mL) -group A versus C -group B versus D

							Mobility (%) -group B versus C -group C versus D Vitality (%) -A versus C group -C versus D group Morphology (%normal) -A versus B group -A versus C group -A versus D group -B versus C group -group B versus D

3-Effect of mobile phone usage on semen analysis in infertile men S. Sajeda 2011 (4)	Cross-sectional study In vivo	Mean age (29,87+/-6,4)	Mobile phone on	Chronic	300 patients 4 groups according to duration of use per day : -group 1: 4h/d n=50 -group 2: 3h/d n=64 -group 3: 2h/d n=156 -group 4: no use n=30	Sperm parameters -volume -count (Millions/ml) -Mobility (%) -Morphology (%normal)	Univariate analysis Difference between groups compared with group 4 : NS not significant p>0.001 Significant p<0.001 Volume (ml) -Group 1: 2.82 +/- 0.64 NS -Group 2: 2.59+/-0.59 p<0.001 -Group 3: 2.64+/-0.46 NS -Group 4: 2.7 +/- 0.39 Count (Millions/ml) -Group 1: 16.04 +/- 3.45 p<0.001 -Group 2: 18.96 +/- 5.62 p<0.001

					2 groups according to duration of use in years: -group A: 1 to 3 years n= 157 -group B: 4 to 6 years n=113 Position of mobile phone : -group C: trouser pocket n=112		-Group 3: 25.87 +/- 5.49 p<0.001 -Group 4: 36.166 +/- 5.56 Mobility (%) -Group 1: 31.12 +/- 7.42 p<0.001 -Group 2: 37.66 +/- 8.63 p<0.001 -Group 3: 45.56 +/- 3.69 p<0.001 -Group 4: 51.133 +/- 1.85 Morphology (% normal) -group 1 versus 4: 44.12 +/- 4.57 p<0.001 -group 2 versus 4: 50.14 +/- 6.40 p<0.001 -group 3 versus 4: 56.08 +/- 5.33 p<0.001

					-group D: fanny pack n=127 -group E: shirt pocket n=30		-group 4: 62.2 +/- 7.2 Duration of use in years : Group B -Volume: 2.69 +/- 0.62 NS VS Group A -Blood count: 17.54 +/- 4.80 p<0.001 VS group A -Mobility: 34.76 +/- 8.72 p<0.001 VS group A -Morphology: 47.34 +/- 6.21 p<0.001 vs group A

4-Mobile phone electromagnetic waves and its effect on human ejaculated semen: An in vitro study Veerachari Srinivas Belur 2012 (8)	Experimental study In Vitro	Age not specified	Mobile phone on Sony Ericsson 900 MHz	Acute Exposure time 60 min	23 healthy donors and 9 patients Samples collected by masturbation Each sample = 2 control/exposed aliquots -Aliquots of sperm exposed to a Sony Ericsson 850	Sperm parameters -Concentration (Millions/ml) -Mobility (%) -Vitality (%) -ROS (chemiluminescence technique) (cpm)	Univariate analysis Comparison of exposed versus unexposed groups Concentration (Millions/ml) Non-significant difference -unexposed: 50.65 +/- 16.96 -exposed: 50.55 +/- 17.16 Mobility (%) Significant difference p<0.001 -unexposed: 53.05 +/- 9.29 -exposed: 45.75 +/- 7.49

					MHz mobile phone -Aliquots of unexposed semen		Vitality (%) Significant difference p<0.001 -unexposed: 51.3 +/- 5.77 -exposed: 47.7 +/- 5.24 ROS (number of photons per minute) Significant difference p<0.001 -exposed: 38.1 +/- 27.51*10*6 -unexposed: 31.75 +/- 26.03*10*6

5- In vitro effect of cell phone radiation on motility, DNA fragmentation and clusterin gene expression in human sperm Zalata Adel 2015 (9)	Expérimental study In Vitro	Age not specified	850 MHz mobile phone with maximum power <1W	Acute Exposure time 60 min Distance 10cm	124 semen samples grouped into 4 categories -N Normozoospermia n=26 -A Asthenospermia n=32 -AT Asthenospermia Teratospermia n=31 -OAT	Sperm parameters -Concentration -Morphology -mobility -linear velocity	Univariate analysis Comparison of exposed versus unexposed groups Mobility (%) p<0,05 -N group : Non-exposed 60.8 +/- 4.5 Exposed 56.5 +/- 4.2 -Group A Unexposed 30.9 +/- 5.4 Exposed 26.5 +/- 5 -Group AT Not exposed 23.3 +/- 9.4 Exposed 18.4 +/- 11.9 -OAT group

					Oligospermia Asthenospermia Teratospermia n=35 Each sample divided into 2 (exposed / unexposed)		Not exposed 17.7 +/- 10.9 Exposed 12.7 +/- 7.9 Linear velocity (%) p<0,05 -N group : Unexposed 59.6 +/- 8 Exposed 56 +/- 8.4 -Group A Unexposed 44.9 +/- 14.7 Exposed 39.1 +/- 12.8 -AT group Not exposed 25.5 +/- 11.7 Exposed 20.67 +/-9.5 -OAT group Not exposed 23.8 +/- 13.6 Exposed 16.6 +/- 9.4

6- Mobile phone radiation induces reactive oxygen species production and DNA damage in human spermatozoa in vitro De Luliis Geoffry N. 2009 (5)	Expérimental study In vitro	Mean age (24,1 +/- 1,1)	Night-time exposure to 1.8 GHz electromagnetic radiation over a range covering the emission characteristics of mobile phones	Acute (exhibition during 16h)	2 groups : 22 patients -Control group -Exposed group	Sperm parameters : -mobility -vitality -ROS (expression of the oxidative marker 8-OH-dG)	Univariate analysis Differences between controls and exposed Mobility (%) : significant decrease between the 2 groups p<0.01 -control group: 82 +/- 4 -exposed group: 28 +/- 1 Vitality (%): significant decrease between the 2 groups p<0.01 -control group: 82 +/- 4 -exposed group: 29 +/- 4

							ROS (%): significant increase between the 2 groups $p<0.001$ -Control group: 7 +/- 0.4 -Exposed group: 28 +/- 1

Table 3

Results in animals							
Titre, 1er auteur, année	Type of study	Animal type	Nature of exposure	Type of exposure	Comparison / groups	Judging criteria	Results (95% CI)
7-Oxydative stress-mediated alterations on sperm parameters in male Wistar rats exposed to 3G	In vivo	rats	3G mobile phones switched on (2110 to 2170 MHz) Duration: 45 days (2h / day)	Chronic	Control/exposed 8 rats per group	Sperm parameters -Epididymal sperm count -Head morphology	Difference between controls and exposed subjects Epididymal sperm count Significant difference between the 2 groups $p<0.05$ -Control 62.38 +/- 1.9 -exposed 54.79 +/- 1.74

mobile phone radiation Gautam Rohit 2019 (7)			In a rectangular Plexiglas box			-Vitality (%)-ROS chemiluminescence technique	Head morphology Non significant difference (control/exposed) total anomalies 0.62 / 0.92 Vitality (%) Significant difference between the 2 groups $p<0.05$ -Control 70.13 +/- 1.26 -Exposed 63.63 +/- 1.8 ROS (number of chemiluminescence RLU) Significant difference between the 2 groups $p<0.05$

							-Control 5 RLU -Exposed 6 RLU
8- Radio frequency electromagnetic radiation (RF-EMR) from GSM (0.9/1.8GHz) mobile phones induces oxidative stress and reduces sperm motility in rats	In vivo	rats	Mobile phone switched on (0,9 / 1,8 GHz) Plastic cages	Chronic	2 groups -Control (group I) / -Exposed (group II) 6 rats per group Exposure : For 1 hour continuously per day for 28 days	Sperm parameters -Sperm count -Mobility	Difference between controls and exposed patients Blood count (10*7/ml) Non-significant difference between the 2 groups p=0.052 -Control 7.8 +/- 0.21 -Exposed 7.6 +/- 0.13 Mobility (%) Significant difference between groups p<0.002

Mailankot Maneesh 2009 (10)							-Control 71.97 +/- 8.7 -Exposed 43.08 +/- 10.03
9-The Effects of Cell Phone Waves (900 MHz-GSM Band) on Sperm Parameters and Total Antioxidant Capacity in Rats	In vivo	rats	Vertical antenna : Simulated mobile phone waves frequency 915 (phone waves) MHz and 950 MHz (phone antenna waves)	Chronic	28 rats divided into 4 groups of 7 rats -group 1: control, no exposure -groupe 2 (915 MHz) : 14 days	Sperm parameters -Mobility (%) -Vitality (%) -Sperm count (10*6) -Morphology (%normal)	Differences between groups : Mobility (%) Significant difference p<0.05 Comparison of groups to group 1 -Group 1: 49.96 +/- 4.59 -Group 2: 40.91 +/- 4.11 -Group 3: 32.91 +/- 4.09 -Group 4: 41.29 +/- 6.41

Masoud Ghanbari 2013 (11)					-groupe 3 (915 MHz) 21 days -groupe 4 (950 MHz) : 14 days		Vitality (%) Significant difference p<0.05 -Group 1: 87.64 +/- 1.82 -Group 2: 81.14 +/- 2.87 -Group 3: 74.71 +/- 2.8 -Group 4: 81 +/- 6.61 Numbers (10*6) Non-significant difference p>0.05 -Group 1: 58.56 +/- 6.01 -Group 2: 62.14 +/- 8.92 -Group 3: 57.72 +/- 8.05 -Group 4: 60.19 +/- 6.94 Morphology (% normal) Non significant difference p>0.05

							-Group 1: 82.06 +/- 4.6 -Group 2: 81.78 +/- 3.96 -Group 3: 79.7 +/- 6.61 -Group 4: 83.37 +/- 6.04
10-Whole-body microwave exposure emitted by cellular phones and testicular function of rats S. Dasdag 1999 (26)	In vivo	rats	4 types of mobile phone with Frequency 890-915 Hz (217 Hz modulation) Max power 2W Phone on standby and switched on Animals kept in Plexiglas cages	Chronic	Exposure : 2 hours a day for 1 month 3 groups of 6 -Control group N=6: phone on standby for 2 hours	Sperm parameters -Epididymal sperm count -Morphology	Epididymal sperm count (10*6/ml) No significant difference p>0.05 mean -Group 1: 236.3 -Group 2:219 -Group 3:209.8 Morphology (%normal) No significant difference p> 0.005 mean -Group 1: 85.7 -Group 2: 88.7

					-Experimental group 2 : N=6 telephone in speaking position ->phone on standby turned to voice position 3 times for 1 minute over 2 hours -Experimental group 3 :		-Group 3: 84

					telephone in talk position ->telephone in the on position turned to the voice position 3 times for 1 minute over 2 hours		
11-Effects of monochromatic light sources on sex hormone levels in serum and on semen	In vivo	ganders	3 monochromatic light sources - blue 460 to 475 nm , -red 620 to 630 nm ,	Chronic 24 weeks (6-week adaptation period followed by	3 groups of 10 ganders / light Exposure : 7 hours of light per day	Sperm parameters -Volume (ml) -Mobility (%)	Volume (ml) Non-significant difference P>0,05 -blue group: 0.1 +/- 0.1 -red group: 0.1 +/- 0.1 -white group: 0.1 +/- 0.1

quality of ganders Shen-Chang Chang 2016 (12)			-white 520 to 530 nm Produced by fluorescent tubes Animals kept in steel cages	24 weeks of exposure)	For the first 6 weeks Then 9 hours of light a day -group 1: exposed to blue light -group 2: exposed to red light -group 3: exposed to white light	-Number of spermatozoa (10*8/ml) -Vitality (%) -Morphology (%normal) -Morphology (%normal) -Spermatozoa alive and with normal morphology (%)	Mobility (%) Significant difference p<0.05 -blue group:25.6 +/- 3.1 -red group:32.4 +/- 3.1 -white group:44 +/- 3.1 Sperm count (10*8/ml) Non significant difference P>0,05 -blue group: 0.6 +/- 3.1 -red group: 1.3 +/- 3 -white group: 1.1 +/- 3.2 Vitality (%) Significant difference p<0.05 -blue group: 28 +/- 4.9

							-red group: 42.5 +/- 4.7 -white group: 53.7 +/- 5 Morphology (%normal) Significant difference p<0.05 -blue group: 32 +/- 5.7 -red group: 47.5 +/- 5.4 -white group: 55.1 +/- 5.8 Abnormal morphology (%) Non-significant difference p>0.05 -blue group: 8.3 +/- 1.8 -red group: 13.3 +/- 1.7 -white group: 12.5 +/- 1.8

							Live spermatozoa with normal morphology (%) Significant difference p<0.05 -blue group: 16.6 +/- 3.7 -red group: 24.3 +/- 3.6 -white group: 34.7 +/- 3.9
12- Effects of cellular phone emissions on sperm motility in rats Yan Ji Geng 2007 (13)	In vivo	rats	4 types of mobile phone NOKIA 3588i Rats exposed in a PVC plastic holding tube	Chronic	2 groups: 16 rats -Group 1 control (unexposed) n=8 -Group 2 n=8 (exposed) Exposure -per day :	4 Sperm parameters : -mobility (%) -vitality -morphology (%deformation) -total number of spermatozoa (mean 10*7/ml)	Mobility (%) Significant difference between the 2 groups p<0.05 -Group 1: 70.93 +/- 12.94 -Group 2: 44.88 +/- 20.66 Morphology (%deformation) Non-significant difference between the 2 groups p>0.05 -Group 1: 32.1

					-3 hours exposure followed by 30 min rest outside the tubes -Then second exposure >3h/d -Total duration: 18 weeks		-Group 2: 34.3 Total number of spermatozoa in the testicles (mean 10*7/ml) Non-significant difference between the 2 groups p>0.05 -Group 1: 7.7 +/- 8.11 -Group 2: 7.45 +/- 1.03