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Review Article

A Review: Biological Effects of Magnetic Fields on Rodents

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Abstract: This review is aimed to summarize the experimental researches in the influences of Static Magnetic Field (SMF), Pulsed Electromagnetic Field (PEMF), and Radio Frequency Electromagnetic Field (RF-EMF) on laboratory rodent models reported by laboratory scientist, experimental technicians, physicians, veterinarians and other researchers. Past studies suggested that, the application of SMF, PEMF and RF-EMF on rodents were influences the body functions such as hypertension, musculoskeletal disorders, nerve functions, glucose and lipid metabolism, bone disorders, tissue growth, fertility, reproduction, growth. But on the other hand some harmful events have also been observed in number of investigation. So exposure to different types of magnetic field have dual effect on experimental rodents, where positive effect on whole body system are clearly carried out in SMF studies compare to PEMF, RF-EMF. In this, SMF of moderate intensity strength provide beneficial effect on alteration in metabolism of rodents. Further researches need to perform with moderate intensity SMF should provide suitable alternate therapy for metabolic disorders in future clinical trial.
Keywords: Static magnetic field, Pulsed electromagnetic field, Radio frequency electromagnetic field, Metabolism, Rat, Mice

Introduction:

Bioelectromagnetics is the study of interaction between non-ionizing electromagnetic field and biological system. In recent year several studies have suggested, possible bio effect of magnetic fields on rodent. Application of magnetic field to treat disorder in human is one of the most promising complementary/alternative and conventional medicines. Since it provide non invasive, easy and safety. In fact, ancient China, Japan, and Europe use natural magnetic material to treat disease such as headache, oedema, and rheumatism, but also cure paralysis. The mechanism of treating disorders may be mediated by stimulation of increased blood due to alteration of calcium ion in muscle.

Past few decades hundreds of experiments have been carried out on animals to asses biological effect of exposure on different types of magnetic field such as permanent/SMF, low frequency sine waves, PEMF, RF-EMF, transcranial electric/magnetic stimulation. In this review SMF, PEMF and RF-EMF are included in this studies due to most of the work performed on these types of magnetic field while, others are excluded from this studies due to deficiency of data. Results obtained from these studies shows most has beneficial effect and some has negative effect.

Under these conditions most experimental results carried over year for bio effect of different magnetic field on rodents. Because rodents are similar in genetic resemble with human as well as some advantage in reproducibility and also well developed disorder model with low cost. To the best knowledge experiment on effect of various magnetic fields were rapidly increased after the Second World War [1]. Out of this, experiment by using SMF on rodent has rapidly discussed in detail and reported, the effects were compared to experiment on PEMF and RF-EMF.

Some article reviewed the effect of SMF, PEMF, RF-EMF at *in vivo* models [2-5]. To date there is no summarised review regarding different types of magnetic field experiment on biological system in rodent models. So the primary objective of this review is to sum up the literature concerning bio effect of

different types of magnetic field on rodent and to optimize the magnetic field in future treatment.

Bio effects of Magnetic Field:

As one of the physical factors of environment, like air pressure and temperature, geomagnetic field 30-70 μT (micro Tesla) plays an important role on living and evolution for organism on earth [6,7]. All living being are sensitive to magnetic field. This can be possible by two mechanism due to presence of magnetic nanoparticle like Fe_3O_4 (magnetite) and also influenced by chemical reaction occur in living organism [8]. Increasing interest in application of magnetic field in complementary/alternative and conventional medicine has attracted the scientist for various disorders. Electromagnetic field on biological effect can be categorized into five groups based on therapeutic utilities such as: permanent/SMF, low frequency sine waves, PEMF, RF-EMF and transcranial electric/magnetic stimulation [1].

Numerous publications discussed the possibilities of exogenous magnetic to initiate beneficial effect on various biological processes, which are importance for healing of different injuries and pathologies [9]. Their results are discussed in table 3, 4, 5. According to their frequency, electromagnetic fields are classified into four types by European commission of non ionization radiation, which are mentioned in table 1. They are SMF, low frequency magnetic fields, intermediate frequency magnetic fields, RF-EMF [10].

Table 1: Types of Magnetic Field and their frequency

S.No	TYPES OF MAGNETIC FIELD	FREQUENCY RANGE
1.	Static magnetic field	0HZ
2.	Low frequency magnetic field	0-300HZ
3.	Intermediate frequency magnetic field	300HZ-100KHZ
4.	Radio frequency electromagnetic field	100KHZ-300GHZ

Corresponding to therapeutic utility SMF, PEMF and RF-EMF are mainly discussed in this review due to numbers of availability of results and focused on them to show integrated concept on biological system. Low frequency sine wave and transcranial magnetic stimulation are excluded due to data deficiency. Here we give brief introduction for different types of magnetic field on their bio effect and more detailed sub types explained individually on their following topic.

Static Magnetic Field:

SMF can be created by various permanent magnets as well as by passing direct current through a coil [1]. It can be characterized by frequency of (zero) 0 Hz and not varying with time during production of magnetic field [11]. Bio effect of SMF on animal model since 1948 [2]. Due to development of animal model for various disorders, examination on bio effect of magnetic field rapidly increased. SMF have different therapeutic effect in animals including anti inflammatory, pain relive, antibacterial effect, but SMF also have therapeutic effect in different system of rodent has been examined [3], which are seen in table 3.1 and 3.2. The application of SMF has increased for treating some specific medical problems during last three decades. SMF can be easily penetrated into biological tissue through several physical mechanisms. So that SMF are widely used throughout the world [12]. Several clinical studies are described in table 3.1, 3.2, 4, 5. Due to diverse response is of SMF on biosystem of living organism, it can be classified as various intensity ranges are given in table 2.

Table 2: Types of Static Magnetic Field and their intensities [9]

S.NO	SMF	INTENSITY RANGE (mT-milli Tesla, T-Tesla)
1.	Weak intensity	Less than 1mT
2.	Moderate intensity	1mT - 1T
3.	Strong intensity	1T - 5T
4.	Ultra strong intensity	More than 5T

Weak Intensity SMF:

SMF produced is less than 1mT known as weak intensity SMF. This intensity magnetic field also expressed as μT (micro Tesla) range. Normal metabolism in living organism is occurred, which are frequently exposed to this intensity range because of geomagnetic field 50μT [7]. Apart from that only limited numbers of studies are carried out by using Weak Intensity SMF.

Novikov *et al.,* [13] have used an experimental model of carcinoma bearing mice to examine the effect of weak intensity SMF. Particularly weak intensity SMF exposed to normal animal shows no harmful effects on major organs and tissue. In addition, no pathological deviations were observed. Weak intensity SMF exposed on experimental model of carcinoma bearing mice cause degradation of tumour size initiated by autolytic enzyme and then cells are lysed. Simultaneously it activates antitumor immunity; particularly it stimulates the production of tumour necrosis factor this leads to elevate the level of local concentration of reactive oxygen species. There by producing anticancer activity. Finally the result showed that exposed mice had a decrease the incidence of tumour growth and an increase in longevity. Further research by Lerchl *et al.,* [14] have suggested that application of 80μT SMF cause effect in mammalian pineal gland. Because pineal gland is sensitive to magnetic field of spatial orientation. Based on their finding the result suggested that artificial SMF cause change in pineal indole metabolism. When a tissue exposed to altered magnetic field cause production of eddy current. An induced eddy current may affect nervous system.

Table 3.1: **Bio effects of Static Magnetic Field**

TYPES OF SMF	BIOLOGICAL EFFECT	EXPOSURE PARAMETERS	REFERENCE
Weak intensity (less than 1 mT)	Decrease volume of tumour and increase longevity	Mice - 42μT, 1h a day for 12 days	13
	Influence of action on pineal gland	Rats - 80μT, 1h	14
Moderate intensity (1mT – 1T)	Cause temporary diabetic like state	Rats - 1mT/10mT, 1h a day for 10 days	23
	Changes occur in haematological and biochemical parameter	Rats - 128mT, 1h a day for 5/30 days	15
	Alteration in glucose and lipid metabolism	Rats - 128mT, 1h a day for 5/15 days	12
	Changes in glucose and lipid parameters of serum and skeletal muscle	Rats - 128mT, 1h a day for 15 days	9
	Metabolic alteration	Same as above	11
	Anti-oxidant activity	Rats - 128mT, 1h a day for 30 days	16
	Biochemical parameters change due to up regulation of norepinephrine concentration	Rats - 128mT, 1h a day for 5 days	24
	Increasing immune function	Mice - 200-400mT, until death	25
	Changes occur in behavioural response	Rats - 128mT, 1h a day for 5 days	26
	Alteration of inorganic ion content in spinal cord, medulla	Same as above	27
	No influence on spermatogenesis	Rats - 128mT, 1h a day for 30 days	28
	Antidiabetic effect	Diabetic mice - 2.8 to 476.7mT, 30 min a day for 12 weeks	29
	Produce Analgesic effect due to alteration in blood circulation	Rats - 200 mT for 4 weeks	30
	Anti-oxidative function on blood	Rats - 128 mT, 1h a day for 5 days	31
	Alters blood pressure associated with Nicardipine	Rats - 180 mT, 1h a day for 8/6 weeks	32,33
	Limited Alteration in hearing	Mice - 5mT, 2h a day for 2 weeks	34

Moderate Intensity SMF:

Moderate intensity SMF is characterized by permanent magnet which produces the magnetic field limit of 1mT-1T. Normal whole human body safety exposure limit were set up to 400mT of Moderate intensity SMF [7]. Number of the studies were conducted between these exposure limit cause biological effects on most of the system in rodents. According to researchers (Gorczynska and Wegrzynowicz, [23], Elferchichi *et al.,* [11], Laszlo *et al.,* [29], Amara *et al.,* [15], Elferchichi *et al.,* [9], Lahbib *et al.,* [12]), experiment conducted by using magnetic field less than 200mT is suitable for metabolic alteration in living organism.

Gorczynska and Wegrzynowicz, [23] have researched the biological effect of SMF on rats exposed to 1mT and 10mT. The data showed that, it cause temporary diabetic like state due to hyper function of adrenal, thyroid and pituitary glands and also pancrease. Hence, the release of insulin got decreased while glucagon content was increased. It seems that metabolism of glucose is similar to diabetics. It has been suggested that reduction of insulin release may be decrease in calcium efflux of islet cell caused by magnetic field. Further magnetic field creates hydrophobic property of cell membrane and this will affect the glucose transport across cell membrane.

Elferchichi *et al.,* [11] concluded that there were significant difference in treated and control group after exposure to 128mT SMF using rat. These shows prediabetic like state , when metabolic alteration were induced by moderate intensity SMF could develop. Moreover, it is important to note that hyperglycemia due to conformational changes occur in insulin by magnetic field exposed animals. It will leads to reducing the binding capacity of insulin particularly at hepatocytes and results in hyperglycemia. Additionally, rose in blood glucose also caused by epinephrine. While study conducted by Laszlo *et al.,* [29] observed the decrease in blood glucose level on repeated exposure of moderate intensity SMF in diabetic mice. This indicating the promising application of SMF for future treatment subsequently this study shows improved diabetic wound healing rate. From the above studies both positive and negative effects in glucose metabolism influenced by SMF, because it was based on magnetic field strength.

Amara *et al.,* [15] conducted an experiment on rat blood which is exposed to 128mT intensity. Sub acute exposure of SMF reduces body weight of animal and the same treatment will cause increase of white blood cells, red blood cells, platelets and haemoglobin concentration while hematocrit level unchanged. This could be probably due to hypoxia status. Whereas increased in blood glucose level observed in magnetic field exposed rat could be related to the structural and functional changes in pancrease. The results were shows that alteration in haematological and biological parameter due to proliferation of blood cells and enzymes release in blood related to duration of exposure. Similar work has been carried out by Ghodbane *et al.,* [16, 31] in addition with selenium were included in their study. Because magnetic field treatment reduces selenium in major organs like kidney, brain and muscle. Hence combine effect of selenium and SMF should increases the antioxidant activity minimize the oxidative stress which is induced by SMF in rat. The result proposed by means of examine the antioxidant materials like tochopherol, retinol, glutathione peroxidise.

Lahbib *et al.,* [12], Elferchichi *et al.,* [9] observed the glucose and lipid parameters (glucose, cholesterol, phospholipids, triglycerides) in serum and skeletal muscle, and also glycogen content in liver and muscles by using rat as an experimental model exposed to moderate intensity SMF of 128mT. This cause hyperglycaemia attributed due to increased release of hyperglycaemic hormone (glucagon) and/or inhibition of hypoglycaemic hormone (insulin). Whereas lipid metabolism also altered because of membrane integrity. The decrease of body weight might be due to reduction in body fluid and protein content including hormonal changes and relatively loss in liver weight were also observed. In tissues, SMF exposure showed significant alteration in enzyme activities. The data showed that SMF effects on glucose and lipid metabolism and in addition, the conducted investigation on rat to examine the effect of SMF on loss in body weight. Therefore moderate intensity SMF seems to have anti-obese effect.

A study was carried out by Abdelmelek *et al.,* [24] on skeletal muscle of rats were induced by moderate intensity SMF for 5 days. The result showed that 128mT cause effects in regulation of norepinephrine concentration. This may affect increase in blood pressure but no changes were observed in growth rate. The basic mechanisms involved in changing the norepinephrine concentration were caused by magnetic field of electro sensitive ion channels on plasma membrane. Yang *et al.,* [25] have used an experimental model of mice to examine the effects of moderate intensity SMF. Mechanism of antitumor activity may be mediated by enhancing the cell proliferation and decreasing the affected cell number

significantly. The findings suggested that, life time was prolonged significantly in leukaemia infected mice by upregulating the function of immune system for certain period of time.

Amara *et al.,* [28] studied the sub chronic effects of SMF exposure on testicular function by examine the sperm count, genital organ weight and sperm motility. Finally they concluded that there were no significant changes occur between control group and treated group on spermatogenesis in rat testes.

Ammari *et al.,* [26] studied the relationship of rat behavioural response and moderate intensity SMF using 128mT fields 1h a day for 5 days, behavioural response were checked by an experimental model of learning abilities in morris water maze, emotional behavioural testing, elevated plus maze and open field. They found some effects of moderate intensity SMF on rats. Miryam *et al.,* [27] they perform similar exposure condition on the effect of moderate intensity SMF in medulla spinalis. The treatment has resulted in variation of ion concentration of medulla spinalis which shows Ca^{2+}, Fe^{+} concentration increased rapidly while no change in magnesium and copper. Moderate intensity SMF cause raised blood circulation and bone mineral density which is mediated by absorption of Ca^{2+} ion in oesteoblast of bone, this leads to increasing locomotors activity. Therefore moderate intensity SMF has analgesic action Kanai and Taniguchi, [30] studied the influence on experimental rat models. These authors suggest that exposure to SMF may induce cholinergic nerves by reducing cholinesterase activity and that results in release of acetylcholine induce elevated blood flow.

A study by Okano & Ohkubo, [32,33] investigated the influence of combined effect of moderate intensity SMF upto 180mT and Nicardipine (Ca^{2+} channel blocker). The results found that they cause significant change in hypertension which can be mediated by clogging Ca^{2+} flux and up regulation of nitrous oxide metabolites. In case of animal exposed to magnetic field alone were significantly reduced or delayed the hypertensive development. But combined effect of SMF and Nicaripine shows increased reduction of blood pressure on rats. SMF induces raised NO level in plasma with Nicardipine. The reasons beyond these effects were due to elevation of plasma NO synergistically with Nicardipine. Politanski *et al.,* [34] conducted the experiments on mouse to investigate the effects of noise, when mice exposed to 5mT, 2h a day for 2 weeks. The result shows that limited application in hearing. Numerous studies are conducted on various intensities bioeffect on rodents are given in table 3.1

Strong Intensity SMF:

Strong intensity SMF is characterized by permanent magnet which produce magnetic field from 1T to 5T. During past few decades only limited number studies are carried on this type SMF to express their bioeffect on rodent. Tsuji *et al.,* [17] researched the mice behaviour when exposed to 5T for 2 days. They examine weights of major organs in body like kidney, brain, heart, liver, spleen and lungs. However measuring the weights of major organ after magnetic field exposure shows no significant difference on it. But body weight, blood glucose and blood urea nitrogen were altered significantly due to fluid shift and also affect drinking and eating behaviour due to changes in circadian rhythm by exposed SMF. The result showed that SMF affect mice behaviour by decrease eating and drinking and lower body weight due to fluid loss cause increase blood sugar level and blood urea nitrogen after 2 days. Findings of this study show 5T cause direct effect on central nervous system.

Table 3.2: **Bio effects of Static Magnetic Field**

TYPES OF SMF	BIOLOGICAL EFFECT	EXPOSURE PARAMETERS	REFERENCE
Strong intensity (1T-5T)	Decrease food and water consumption, decrease in body weight	Mice - 5T for 24h, 48h	17
	Alteration in pain response	Mice - 3T for 30 min	18
	Changes occur in primary bone marrow cells	Mice - 1.4T for 1h	35
	No changes observed in treated and control group	Mice - 4.7T for 2 days	36
	Alteration in bone marrow	Mice - 3T, 4.7T for 3 days	37
	Activation of intracellular signalling transduction pathways	Rats- 1T for 1h	38
Ultra strong	Change in locomotors activity	Rats - 14.1T for 30/5 min	39, 40
	Behavioural changes	Rats - 14T for 30 min	19

intensity (more than 5T)	Changes blood flow	Rats - 8T for 5 min	20
	Changes behaviour response	Rats - 7T for 30 min	21
	No changes observed	Rats - 9.4T for 10 weeks	22
	Effects on sciatic nerve	Rats - 8T for 1ms	41

Prina-Mello *et al.,* [38] have conducted a study for investigating the effectiveness of strong intensity SMF of 1T because activation of intracellular signalling transduction pathways by means of Extracellular Regulated Kinase and C-Jun N Terminal Kinase on primary cortical neurons was determined. Laszlo and Gyires *et al.,* [18] studied that strong intensity SMF cause alteration in pain response. Summary of strong intensity SMF are given in table 3.2.

Bhatia, [35] assessed the strong intensity SMF in mice on 1.4T cause some changes in membrane and receptors of primary bone marrow cells. In this study temperature dependent effect of magnetic field has been observed. Finding shows phagocytic action on bone marrow cell mediated by action of body temperature of animal not on sex dependent manner. Similar study by Suzuki *et al.,* [37] investigated that strong intensity SMF on mice of 3T, 4.7T for 3 days were influence the alteration in bone marrow cells. Because this study is evaluated for wide spread application of magnetic resonance imaging, nuclear magnetic resonance, electron spin resonance by human beings. Okazaki *et al.,* [36] reported that there were no significant difference observed in treated and control group when mice exposed to 4.7T for 48h. Simultaneously no adverse effects were investigated on fetal development.

Ultra Strong Intensity SMF:

Ultra strong intensity SMF can be categorized based on magnetic field intensity more than 5T produced by permanent magnet. During past 30 years least number of studies is conducted on this type of SMF. Houpt *et al.,* [39, 40, 21] have found the relationship of SMF and behaviour of rat using 14.1T, 7T for 30 or 5 min. The behavioural change was observed by analysing locomotors activity, food and water intake. Decrease in locomotors activity and rearing cause reduction of drinking may due to lower mobility. Finally the concluded that high strength magnetic field cause reduction of food intake. The result showed that ultra strong intensity SMF exposed is directly proportional to altering the behavioural response on experimental rat models.

Cason *et al.,* [19] studied the action of rat for 14T SMF exposed for 30 min shows behavioural changes. Ichioka *et al.,* [20] showed that decrease in skin temperature was measured. This may due to influence in water evaporation when rat exposed to 8T for 5 min. Sekino *et al.,* [41] have performed an experiment for describe the effect of SMF on rats of 8T for 1ms. The data shows that ultra strong intensity SMF cause effects on sciatic nerve potential. High *et al.,* [22] have conducted a study for explaining the effects of ultra strong intensity SMF on rat of 9.4T for 10 weeks observed no significant changes on spatial memory test, body weight, food and water consumption, gross pathological findings, heart rates, terminal hematologic, blood biochemical and urine parameters, feeding ratio and major organ weights. From the past studies we concluded that ultra strong intensity SMF of most of them cause influence in biological effect, while some shows no change in bioeffects. Summary of ultra strong intensity SMF are given in table 3.2.

Pulsed Electromagnetic Field:

PEMF is a low frequency field with varying specific wave shape and amplitude. It is a subset of extremely low frequency electromagnetic field i.e., PEMF display frequency at low end of electromagnetic spectrum from 6Hz up to 500Hz. Waveform associated with PEMF can be asymmetric, biphasic, and quasi rectangular or quasi triangular in shape. Most of the extremely low frequency electromagnetic field produces sinusoidal wave form. Specific type of low level electromagnetic fields produces specific response depend on the parameters of the field eg., magnitude, frequency, waveform [1]. PEMF therapy has been popularized in 1970 due to non invasive method of treatment [3]. The effect of PEMF on biosystem has been extensively investigated. Previous studies have reported that PEMF can stimulate influence of many functions in body such as musculoskeletal disorders [3, 4], nerve growth, and regeneration in animal models [42] which are mentioned in table 4.

Hannan *et al.,* [47] researched that combined treatment of PEMF and anti tumour drug have promising effect in cancer therapy. PEMF treatment on mice for 1h shows alteration in tumour volume. The result shows that PEMF cause synergetic effect on anti tumour drug (cisplatin, carboplatin and doxorubicin). Liang *et al.,* [48] have reported that combined PEMF treatment with anti tumour drug on rats for 3 weeks shows significant reduction in tumour size to either

treatment alone. They reported that combined treatment of PEMF and drug provide best at reducing tumour size and improving survival. Williams *et al.*, [49] conducted an experiment on investigating the effect of PEMF on mice with carcinoma. These researchers found PEMF cause significant reduction of tumour growth and vascularisation. These three studies suggested that survival and tumour can be influenced by PEMF.

A study by Tufan *et al.*, [42] has investigated that (1.5mT, 1h a day for 4 weeks) on neurobiological effect of diabetes induced neuropathy. The result shows that PEMF can provide beneficial effects on symptoms of diabetes hyperalgesia and allodynia. But this also provides partial prevention of hyperglycemia. Fleming *et al.*, [46] found that 20 min exposure to PEMF (5μT, 1sec on and 4sec off) in rats resulted in increased analgesia. This shows that PEMF cause alteration in pain response. Haghnegahdar *et al.*, [50] have conducted an experiment on rat to examine the healing process in periodontitis which can be made available by using PEMF provide by Helmholtz coil. They using PEMF of 50Hz, 97.6μT, 4h a day for 7 days cause simultaneous effects on cells and tissues. The result found that enhanced healing of periodontitis.

Table 4: Bio effect of Pulsed Electromagnetic Field

BIOLOGICAL EFFECT	EXPOSURE PARAMETERS	REFERENCE
Improved speed of nerve regeneration	Rats, diapulse; 65μsec bursts, 80-600 pulse/sec	43
Increase recovery of injured nerve. Improve regeneration of damaged nerves	Rats, diapulse; 400 pulse/sec, 15 min daily for 3.5 days, 1, 2, 3, 4, or 8 weeks	44
Regeneration of sciatic nerve	Rats, 0.3mT, 20 m sec pulse, 2Hz repetition for 1h daily	45
Improved analgesia	Rats, 5μT pulse burst, 1 sec on and 4 sec off for 20 min	46
Alter tumour size when in combination with chemotherapy drugs	Mice, 5.2mT, 250 pulse/sec,120 μsec ramped pulse for 1h	47
Cause changes in tumour volume when combining with anti-cancer drug	Mice, 5.25mT, 250 pulses/sec, 120 μsec ramped pulse 1h weekly for 3 weeks	48
Reduced tumour growth and vascularisation	Mice, 0, 10mT, 15mT, 20mT 120 pulse/sec for 10 min daily	49
Reverse the abnormalities occur in painful diabetic neuropathy	Rats, rectangular wave, 1.5mT, 1h a day for 4 weeks	42
Healing of periodontitis	Rats, 50Hz, 97.6μT, 4h a day for 7 days	50

Wilson and Jagadeesh, [43] have conducted a study to assess the effectiveness on regeneration of nerve in upper limb of rats using PEMF. Histology shows that regeneration of nerve fibres occurred in PEMF treated rats. The data reported that PEMF treatment shows improved speed of nerve regeneration. Further research by Raji, [44] reported that PEMF treatment shows beneficial effect in regeneration of damaged nerve and improve recovery of injured nerve. Histological study on this research shows increase in number of nerve fibres among treated group to sham group. These results suggested that PEMF beneficial in altering nerve repair. Sisken *et al.*, [45] have investigated an experiment by using PEMF (0.3mT, 2Hz, 20ms Pulse) on sciatic nerve damaged rat. The data indicated that PEMF cause influence in improve regeneration of sciatic nerve. Over all these studies suggested that PEMF treatment useful in nerve repair. Summary of PEMF are given in table 4.

Radio Frequency-Electromagnetic Field:

10MHz to 3.6GHz frequency of RF-EMF are included in this study. In RF-EMF, limited research and reviews were reported on biological effect in animal models. Most of the researchers only focus RF-EMF on fertility, reproduction, growth, behavioural effects in rodents. Since effect on popularise over the past few decades due to increasing usage of mobile phones. Past studies reported that RF-EMF influence on body function such as growth, behaviour, and reproduction, which are discussed in table 5.

Yang *et al.*, [51] performed a study to find out whether stress response of rats was affected by RF-EMF. Their study shows that change of normal

physiological function of the hippocampus morphology through increased expression of Heat Shock Protein gene and mRNA respectively. Further immunochemistry of pyramidal neurons was also affected. Poulletier De Gannes *et al.*, [52] has studied the reproductive function of RF-EMF on rat for 2h a day for 18 days. Particularly these were examined by various maternal observations such as mortality, morbidity, body weight, food consumption and also clinical examination. In addition to that, offspring examination like delivery data, body weight, newborns physical and functional observation, clinical and post-mortem examination were done. Finally the result shows no significant alteration of response on reproduction and development. Lee *et al.*, [54] has conducted an experiment on rats exposed for 45 min a day for 12 weeks on RF-EMF. They were examining the sex hormone level by using serum of rat. Then result shows no adverse effect on reproduction.

Table 5: Bio effect of Radio frequency electromagnetic field

BIOLOGICAL EFFECT	EXPOSURE PARAMETER	REFERENCE
Stress response elicited in rat hippocampus	Rats, 2450MHz, 20 min	51
No abnormalities in reproduction and development	Rats, 2450MHz, 2h a day, 6 days/week for 18 days	52
Attains puberty earlier	Rats, 900MHz, 2h a day for 90 days	53
No effect on reproduction	Rats, 848.5MHz, 45 min a day for 5 days/ week, 12 weeks	54
No effects on reproduction and development	Rats, 1950MHz, 5h a day for 7 days/week, 5 weeks	55
Altered behaviour and increased stress	Rats, 900MHz, 15 min	56
Detrimental effects on fertility	Rats, 900–1800MHz, 1h a day for 28 days	57
Unaltered development	Mice , 848.5MHz, 90 min a day (15 min break) for 17 days (gestation period)	58
Abnormal behavioural response to noxious stimuli	Rats, 73.5MHz, 2h a day for 45 days	59
Unaltered learning in the performance of tasks	Mice, 900MHz, 45 min for 10 days	60

Lee *et al.*, [58] investigated the effect of RF-EMF on mice which exposed to 848.5MHz of 90 min a day for 17 days. They reported that mostly no significant alteration of weight gain, clinical signs of toxicity during gestation period, body temperature, and growth of foetus were occur. In addition, some groups shows change in body weight, head length, body length and head width of foetus were observed. From these studies the researchers reported that short term exposure of RF-EMF causes no significant change in alteration of biological effect on rats/mice.

A study was carried out by Sienkiewicz *et al.*, [60] who suggested the performance of mice in eight arm radial arm maze after the magnetic field exposure does not affect the acquisition of learning. Findings of their study on exposed mice show no cognitive impairment. Similar study was conducted by Bouji *et al.*, [56] on rats which show alteration in behavioural response when exposed to RF-EMF. In addition, it could be assessed by using assay of interleukin and corticostrone from brain and plasma of rats respectively. Further emotional memory was also analysed. Finally they conclude that emotional memory was enhanced and corticosterone was impaired but interleukin should only weak. Further research were carried by Mathur, [59] who explored the effect of RF-EMF exposure on rat for 45 days, they suggested that it cause alteration of noxious stimuli. This can be concluding by examine the effect of phasic pain and tonic pain. Their findings reported decreases pain and vocalization in former and exaggerated emotional response to painful stimuli latter. Last three studies show significant changes in behaviour response by RF-EMF.

A research under took by Ozlem Nisbet *et al.*, [53] on rats with sub chronic exposure of RF-EMF, both the testosterone level and sperm motility were determined. They found that testicular function and

sperm motility on rats could cause upto some extent. Hence their findings were due to decline in melatonin concentration and an increase in testosterone concentration. Imai *et al.*, [55] found testis function on rat when exposed to RF-EMF. The data showed that there were no significant effect observed on reproduction and development like body weight gain or weight of the testis, epididymis, prostate, seminal vesicles and sperm count. Findings of this study show no testicular toxicity was evident. Mailankot *et al.*, [57] have conducted a study for investigating the effectiveness of RF-EMF on rats which exposed for 4 weeks. They found that in rat were influenced the reproductive function on treated group. This RF-EMF seems to have changes on oxidative stress and decreasing sperm motility. From these three studies shows altered reproductive function by RF-EMF based on its strength. Summary of RF-EMF are given in table 5.

Conclusion:

This review was under taken to summarize SMF, PEMF and RF-EMF on bio effect in rodents. All types of magnetic field show both beneficial and adverse effect on biological system, even no bio effects were also observed. Studies in the past few decades on SMF influence most of the biological system in rodents. In this moderate intensity SMF have good metabolic alteration. Most of the studies in PEMF show beneficial effect in musculoskeletal disorder, nerve function. While RF-EMF were mostly shows bio effect by means of altering the behavioural response. Compare with these three types of magnetic field, moderate intensity of SMF shows more benefit for metabolic disorders because, individual magnetic field cause more beneficial effect with some side effect. In order to overcome this side effect combined effect of magnetic field with western medicine is one of the method and this should provide effective magnetic therapy in future treatment.

Magnetic fields are used in the treatment of Osteoarthritis, Polyarthritis, Fracture, Parkinson's Disease, Alzheimer's Disease, Hemiplegia, Diabetic Ulcer. At present there is no specific drug is available for short term treatment of metabolic disorders like obesity. From this review we conclude that, magnetic field of moderate intensity SMF shows beneficial effect in alteration of both glucose and lipid metabolism. It can provide viable alternate therapy for treating metabolic disorders. Hence, Magnetic field in combination with drugs has potential to induce synergistic effect for treatment of various diseases and to reduce the side-effects of particular drugs.

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