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Review

Static Magnetic Field Therapy-A Review

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Abstract

Magnetic field therapy, a non invasive, complimentary therapy that uses a low- frequency magnetic field, has been officially approved by US Food and Drug Administration (FDA) for orthopedic applications, in treating pain and edema in superficial soft tissues. Static magnetic field therapy (SMFT) is produced by permanent magnets and is considered relatively safe because no electromagnetic radiation is emitted. SMFT has shown different therapeutic effects in humans and animal models including anti-inflammatory, pain relieving, antibacterial and inhibition/excitation effects in different systems including cardiovascular, skeleton, endocrine and reproductive systems. SMFT in veterinary practice is primarily restricted to musculoskeletal injuries. Despite high therapeutic utility both in veterinary and human medicine, optimal MFT dosage and treatment parameters like frequency, intensity and exposure time, have not been established for each clinical condition.This review was contemplated to explore the role of magnetic therapy in healing including fracture repair and to gain an insight into the mechanism of action of magnetic therapy along with its safety concerns.

Keywords: Fracture Healing, Static Magnetic field therapy, Magneto therapy.

Introduction

Healing process is a natural phenomenon that maintains tissue homeostasis. However, there are various factors that affects such a process and in order to enhance healing and to reduce man hour loss, morbidity, and make the therapy economical, advances in the field are being sought. One of the ways is the magnetic field therapy, a non-invasive, cheaper and highly adaptable technique that is preferred over pharmacological and/ or surgical procedures both by a clinician and a patient (Peng *et al*., 2019). This therapy utilizes magnetic field as a therapeutic agent and affected part is just exposed superficially without any invasion (Mikesky and Hayden, 2005). This therapy involves use of pulsed electromagnetic field therapy (PEMFT) and static magnetic field therapy (SMFT) (Saifzadeh *et al*., 2007). Low-frequency magnetotherapy is officially approved by US Food and Drug Administration (FDA) for orthopedic applications, in treating pain and edema in superficial soft tissues (Markow, 2007). Magnetic therapy is used as a complimentary therapy in veterinary (Gaynor *et al*., 2018) and human medicine (Luigi and Tiziano, 2020), especially for musculoskeletal disorders and pain management. This review of literature is aimed at exploring the magnetism in relation to the healing process and its efficacy in different musculoskeletal disorders.

Magnets and their Properties

Magnetic Materials

Magnetic fields created by magnetic materials are closely related to the survival and evolution of creatures on earth because all organisms are under a geomagnetic field, as magnetism also arises from moving electrons, and cells, tissues, and organs have magnetic fields of their own (Lohmann, 2010). Static magnetic fields (SMFs) are produced by permanent magnets. Modern therapeutic magnets are constructed of synthetic alloys with inherently strong, permanent, static fields and controllable shapes as films, scaffolds, and implants to meet different needs. These are prepared by co-precipitation, micro-emulsions, thermal decomposition, ultrasonic irradiation, and sol–gel reactions (Wu *et al*., 2016). Magnetic alloys are categorized by the material content. Compounds of aluminum, nickel and cobalt (alnico) are sometimes mixed with iron, copper or titanium to create field strengths of up to 0.15 T. Rare earth or super (lanthanoid) magnets when blended with neodymium and sometimes iron and boron are typically of 0.2 to 1.2+ T, or, with samarium cobalt can be even stronger, up to 3.4 T (Laakso *et al*., 2009). Rare earth permanent magnets, made from elements samarium cobalt (SmCo5) and neodymium iron boron (Nd2F14B) can be fabricated in small sizes due to their high maximum energy product value and high resistance to demagnetization, are used for various medical and dental applications (Bondmark *et al*., 1995), as these provide a sufficient mechanical force for prosthesis retention and tooth movement constant force for a number of cycles (Lew *et al*., 2021).

Static magnetic fields (SMFs), produced by permanent magnets generally bring several intriguing advantages to clinical applications, such as needing no powered device and being able to noninvasively penetrate tissue for stimulation and repair (Marycz *et al*., 2018; Xia *et al*., 2018). Static magnets have a built-in permanent magnetic field having a constant strength which does not change over time, hence never need replenishing. Static magnets are simple to use, non-invasive, cheap and with no known associated risks (Dedmari, 2011).

Magnetic materials produce magnetic fields directly or indirectly. SMFT is produced by permanent magnets. Magnetic fields may also be generated by variation in an electric field (Peng *et al*., 2019). Magnetic materials comprised of various metallic elements [iron (Fe), cobalt (Co), or nickel (Ni)] can be in the form of blocks, membranes or even fluids. Magnetic material remains immaterial in the therapy, what matters is the size of each magnetic particle that influences the properties of whole magnetic composite. The relationship with the size of magnetic particle is inversely correlated i.e., stronger magnetism is generated with smaller particles. Reduction in size of magnetic particle to certain limit invites interference of external magnetic field that changes the magnetic direction popularly known as the “superparamagnetism” (Peng *et al*., 2019). Apart from the particle size, magnetic properties also vary with the magnetic composition (Chaubey *et al*., 2007) and its synthetic process (Clavel *et al*., 2007).

Brief History of Magnetic Therapy

Traditional Chinese Medicine (TCM), East Indian Ayurveda and Native American practices are among the most prominent systems that are practiced throughout the world (Eskinazi, 1998). In fact western medicine is only one of several existing systems of health care that are widely recognized (Udani, 1998; Free, 1998). Magnetic therapies have existed in parallel to these recognized and now a mainstay alternative medicinal treatment health practices (Washnis and Hricak, 1993; Bonlie, 1998), but were not officially named until the 12th century (Washnis and Hricak, 1993; Whitaker and Addderly, 1998). Hippocrates, in 400 B.C. demonstrated the first known use of magnets for therapeutic purposes (Washnis and Hricak, 1993). Roman physicians were first to document use of magnets in treatment of arthritis and gout (Andrews, 1996). The study of the biological effects of magnetism intensified in the 1500's when Paraselsus made use of magnets for treating epilepsy, diarrhea and haemorrhage (Washnis and Hricak, 1993; Whitaker and Adderly, 1998).The earliest use of magnets in veterinary practice dates to 1700's when Elisha Perkins employed the magnetic wedges for disease treatment in horses and humans (Whitaker and Adderly, 1998). The magnetic therapy or its research in veterinary medicine is detailed below:

Healing Mechanisms of Magnets

Magnetism exists in the basic life elements, animal cell and its environment (Bonlie, 1997) that emits electromagnetic energy (Whitaker and Adderly, 1998). The magnetic properties of hemoglobin in the blood were discovered and that fetched Linus Pauling Nobel prize in 1954 (Free, 1998). Most acceptable and comprehensive theory to explain the basis for healing influence of magnets is "*Enhanced Circulation*". As per this theory magnets cause a significant increase in the blood flow at the site of injury. Movement of electrically charged ions of various body fluids increases in presence of magnetic field (Sherwood, 1997). This ensure transport of all the factors necessary for the healing process (Washnis and Hricak, 1993; Whitaker and Adderly, 1998). Static magnetic field, when applied on fractured metacarpus of horse was found to increase significantly blood flow and metabolic activity for ensuring its quick and complete healing (Kobluk *et al*., 1994). Contrarily, scintigraphy did not find any significant increase in the blood perfusion after applying magnetic wraps to the metacarpus in horse for a period of 48 hours (Steyn *et al*., 2000). This observation could be negated on the basis that optimal dosage and treatment protocol, as reviewed by Colbert *et al*., (2007) have not been employed satisfactorily. Magnets exert a natural effect upon the charged particles in the blood, expand vessels, and thereby allows larger quantity of nutrient-rich blood to flow into an area (O'Connor *et al*., 1990; Ksienski, 1992; Trock *et al*., 1994; Garofalo, 1995; Frankel and Liburdy, 1996).This magnetism induced enhanced circulation balances the pH level in the cellular environments and rids body of the toxins by enhanced diffusion of ions across the cellular membrane (Bonlie, 1997 and 1998).

Magnetism also causes hyper-polarization of synaptic membranes, resulting in pain control (Warnke, 1983; Sansaverino, 1990). It also induces biochemical reactions at the cellular level (Madronero, 1990), however, in-depth understanding in such cases remains to be done. Magnetic field therapy is also believed to reduce severity of inflammation as demonstrated by application of SMF (B=25 mT for 30 min). The reduction in the levels of inflammatory markers (fibrinogen), stress markers (ACTH, CORT), and oxidative stress marker Malondialdehyde (MDA) into the blood plasma is reported in rats (Traikov *et al*., 2009). Other mice diabetic study also shows SMF reduces oxidative stress (Feng *et al*., 2022). Magnetic field enhances growth and differentiation of the stem cells towards organ specific lineage as per the available microenvironment. This has been documented through increase in alkaline phosphates and osteocalcin-markers of osteoblastic phenotypes (McDonald, 1993; Guerkov *et al*., 2001; Yamamoto *et al*., 2003; Huang *et al*, 2006; Chiu *et al*., 2007). Osteoblast and fibroblast growth and maturation up-regulates the early release of transforming growth factor beta-1 (Gorczynska *et al*., 1989), type I collagen, osteopontin and alkaline phosphatase in an osteoblast cell culture exposed to a static magnetic field (Huang *et al*., 2006). In the fields of stem cell and tissue engineering too, the bio-effects of SMFs includes modulating individual cell metabolism and improving the regenerative processes in the body (Marycz *et al*., 2018). New therapeutic opportunities have been explored using different SMF strengths to regulate stem cell fate *in vitro* and affect osteogenic, chondrogenic, and adipogenic cells (Marycz *et al*., 2018). Also the turnover rate of fibroblasts may increase upon exposure to magnetic field (McDonald, 2004). SMF of higher strength alters the orientation of macromolecules such as collagen (Dubey *et al*., 1999; Torbet, 1984), hydroxyapetite crystals (Singh *et al*., 2006) and even the cells (osteoblasts) in-vitro (Kotani *et al*., 2002). In addition to the pro-healing effects, magnetotherapy tends to control microbial growth although not against all kinds of microbes. The growth inhibition is directly related to the magnetic field (Fojt *et al*., 2004).

Therefore, the possible mechanistic actions of SMF is inflammation control, enhancement in blood perfusion to the ailing area, improving deranged cellular, biochemical changes and/ or the hyperpolarization. All these features ultimately help in controlling the pain (stress) and enhance healing; however, deep insights in the field are highly desired.

Static Magnetic Field Therapy Utility

Magnetic Dose and its Applications

There is no such thing as a 'unipolar magnet' the term is used to describe the application of one pole to the area to be treated. For a bipolar application both poles are in contact with the part to be treated, such as with a horseshoe magnet (Laakso *et al*., 2009). According to their intensity, SMFs can be categorized as ultra-weak (5 μT−1 mT), weak (1 mT), moderate (1 mT−1 T), strong (1–5 T) and ultra-strong (>5T) (Xia, *et al*., 2018). The SMF intensities in the 0.1-3 T range are currently considered to be safe to human bodies because no severe health consequences have been reported (Zhang *et al*., 2017). Extremely low frequency (ELF) /ultra-weak magnetic fields in the pico tesla and milli tesla ranges are aimed at improving neurotransmission and correcting local immune pathology, respectively (Bistolfi 2007). Commonly, weak static therapeutic magnetic devices are made of ferrite (typically <0.4 T) with a single positive and negative pole (Marycz *et al*., 2018). Moderate intensity SMFis used as a tool to promote new bone formation, prevent bone mineral density decrease, and to induce metabolic activity (Li *et al*., 2019). As per several studies moderate SMF in millitesla can also influence either the generation or reduction of ROS in biological systems thus helping in combating allergic reactions (Csillag *et al*., 2014).

Therapeutic Applications

This alternative medicine is not intended to replace orthodox, traditional medical treatment, but instead potentiate their action (Udani 1998). Magnetic therapy has widely been used in medicine since the twenty-first century in breast-cancer therapy (Zheng *et al*., 2018), treatment of bacterial infections (Xu *et al*., 2019), cardiovascular repair (Vosen *et al*., 2016), neural regeneration (Funnell *et al*., 2019), treat osteoarthritis and inflammatory diseases of the musculoskeletal system, alleviate pain, enhance healing of ulcers and reduce spasticity (Quittan *et al*., 2000), especially in the skeletal system (Thevenot *et al*., 2013). SMFs have shown different therapeutic effects in human and animal models including anti-inflammatory, pain relieving, antibacterial and inhibition/excitation effects in body systems like cardiovascular, skeleton, endocrine and reproductive (Yadollahpour and Rashidi 2014). Permanent or static magnetic field therapy has been mainly evaluated in experimental animals and also in clinical practice for fracture healing by placing them at different sites on and around fracture sites (Darendeliler *et al*., 1995; Dedmari, 2009).

Magnetic field therapy in veterinary practice is primarily restricted to enhance fracture union and for other orthopedic problems such as sprains, ligament injuries and for soft tissue injuries. It is preferred over other methods for relieving a range of equine problems (Bromiley, 1993). In canines, magnets are often used to aid in fracture healing and in the treatment of many other ailments including arthritis, hip dysplasia, osteochondritis, epilepsy, pain relief, chronic organ disorders and vertebral disorders. Sprains and strains and other traumatic disorders have also got benefited from magnetic therapy (Messonier, 2005). Static magnets are now being implanted into the bandaging at the fracture site and reportedly has been resulting a decrease in the healing time of simple fractures by 40-50% in canine (Strazza, 1996).

Orthopedic Applications of SMFT

Fracture-related musculoskeletal diseases have become one of the leading causes of disability, and the number of orthopedic fracture patients worldwide is still accruing (Vas *et al*., 2010). Despite significant improvement in fracture management, 5-10% of all fractures show impaired healing and mostly resulting into non-union (Shi *et al*., 2013; Sibinda *et. al*, 2022). For enhancing and/or accelerating the bone regeneration, thereby shortening the fracture healing duration, decreasing the medical costs and labor losses (Sari *et al*., 2019), magnetic field therapy as a complimentary treatment option is one of the promising modalities (Assiotius *et al*., 2012).

Fracture reduces the bone blood flow in about 50% of its normal capacity at the site of the lesion, thereby retarding the healing process (Busse and Bhandari, 2004). Accelerating the rate of healing of a fracture would not only decrease the duration but also reduce the cost of the treatment (Dedmari, 2011). Magnetic fields increase blood flow at the site of application (attributed to the Hall effect) (Trock, 2000), besides having effects on charged particles or membranes magnets, alter the pH balance of body fluids, alter enzyme activity or other biochemical processes, and disrupt afferent input from free nerve endings of nociceptors (Weintraub *et al*., 2003). The increase in blood flow to an injured site means increased O_2 availability, bringing in of natural healers and removal of toxic byproducts of inflammation, bradykinins and prostaglandins which may speed tissue healing and thus bring fast pain relief (Null, 1998). Furthermore, magnetic fields increase the adherence of calcium ions to the blood clot formed at the site of the break, allowing for the proper formation of the callus for fracture to heal properly (Messonnier, 2001).

Magnetic field therapy promotes the proliferation, orientation, and migration of osteoblast-like cells (Yamamoto *et al*., 2003; Ba *et al.*, 2011; Kim *et al*., 2015), to induce osteogenic differentiation in bone marrow-derived MSCs (Schäfer *et al*., 2010; Kim *et al*., 2015; Huang *et al*., 2017), and to enhance the activity of bone cells and activate remodeling of alveolar bone (Stark and Sinclair, 1987; Darendeliler *et al*., 1995).

Static magnetic therapy has been found successful in the treatment of a number of orthopedic conditions such as un-united fractures (Basset *et al*., 1982; Sharrad, 1990), osteonecrosis (Aaron *et al*, 1989; Basset *et al*., 1989), periarthritis (Leclaire and Borgourin, 1991), osteoarthritis (Trock *et al*., 1994), lumbar fusion (Mooney, 1990) and post-polio conditions (Valbona *et al*., 1997). SMF therapy accelerates fracture healing of osteoporotic rats by increasing the local bone mineral density (BMD) (Yan *et al*., 1998), by regulating the proliferation, morphology and apoptosis of cells (Miyakoshi 2005). SMFs with Fe NPs promotes the formation of new bone through upregulated expression of bone morphogenetic protein (BMP)-2 and enhancement of alkaline phosphatase (ALP) activity, ascribed to Fe NPs becoming super paramagnetic which is conducive to the adhesion and proliferation of osteoblasts (Yuna *et al*., 2016; Zheng *et al*., 2018). SMFs also upregulates expression of collagen type II alpha 1 (COL2A1) and SOX9, which are genes related to chondrogenic differentiation of human bone marrow-derived MSCs, and promote the synthesis and secretion of hyaluronic acid and collagen (Son *et al*., 2015). In vivo and in vitro cellular and membranous clinical research in animals suggest that stimulation using magnetic fields accelerates healing processes (Adey, 2004; Markov, 2006; Morris and Skalak, 2005; Rosch and Markov, 2004).

Static magnets of field strength 0.16T, implanted trans-cortically into the middle diaphysis of rat femurs for a period of 12 weeks yielded the bone of higher Bone Mineral Density (BMD) and Calcium content than the un-magnetized specimen (Yan *et al*., 1998). Magnets having strength 220-260G implanted intra-medullary in osteomized rabbit femur for a period of 4 weeks improved radiologic bone healing with minor effects on bone mineral density values (Nuri and Murat, 2010). Static magnets of strength 41Gauss implanted at the fracture site in rat model for a period of 60 days revealed bone structure exhibiting well organized areas of trabecular bone interspersed with medullary tissue, and blood vessels, adipose degeneration and osteoclastic activity in medullary spaces, suggesting stimulation of bone healing (Puricelli *et al*, 2006). Samarium cobalt magnets of strength 220-260G implanted adjacent to the site of induced radial fracture in adult rabbits for a period of 4 weeks yielded bones, which required significantly greater forces to break bones exposed to magnetic fields (Bruce *et al*., 1987).

The effect of static magnetic field on bone healing in dogs has also been studied with the suggestive conclusion that dogs at risk for delayed healing of fractures may benefit from treatment with SMF. Treatment by custom made magnetic wraps of 1000 Gauss for a period of 8 weeks of a mid-shaft radius osteotomy, resulted in more advanced radiographic and histo-pathological healing of osteotomy sites (Saifzadeh *et al*., 2007). In our own study conducted on rabbit radius fracture model, SMF therapy applied @ 1000 Gauss for longer duration (6hr) enhanced healing of induced complete mid shaft transverse fracture than that of the shorter duration of 2hr or 4hr (Dedmari *et al*., 2022). Combined use of static and pulsed magnetic fields seemingly accelerates the rate of bone repair when compared to the control group (Darendeliler *et al*., 1997).

Autogenous bone marrow concurrent with static magnetic field (2500G) applied continuously for a period of 8 weeks over the bone-defect area in rabbits was found to yield faster bone healing due to more osteoblastic differentiation, blood flow increasing to the defect, the collagen production increase and increasing the adherence of calcium ions to the blood clot in the defective area (Bigham *et al*., 2009). Study conducted over a period of 9 months, treating about 1078 cases of non-union and delayed union showed a 77% success rate (Basset *et al*., 1982).

Safety and Health Concerns of SMFT

The safety and health concerns of the magnetic fields have often been speculated, however, as early as 1979, it was reported that SmCo magnets implanted in tissues did not elicit side effects on blood cells and tissue around the implants (Cerny, 1980). It has also been recorded that the force generated by magnetic materials is more efficacious with less pathological and traumatic changes in oral environment compared with using only mechanical force to move teeth (Tomizuka *et al*., 2006).

SMFs are relatively safe because they do not emit electromagnetic radiation (Peng *et al*., 2019). Low static magnetic field generated by neodymium magnets and ferrite magnets is considered safe by the National Center of Complementary and Alternative Medicine (Marycz, *et al*., 2018). The International Commission on Non-Ionizing Radiation Protection published exposure guidelines for SMFs and set the limit for SMF exposure at 400 mT (International Commission On Non-ionizing Radiation, 1994). A 2-h exposure in a SMF of 3.5–23.0T does not have serious long- term effects on mice (Tian *et al*., 2019), and in other study exposure of SMFs of 2–12T was demonstrated safe (Wang *et al*., 2019). Yet in another study, conducted on rabbits, where SMF therapy was applied @ 1000Gauss 3hours for 21 days for enhancing healing of induced complete mid shaft transverse fracture of radius, haematological indices viz., total leukocyte counts and differential leukocyte counts, and biochemical indices viz., glucose, total protein, albumin excepting alkaline phosphatase contents did not differ significantly from control, thus showing no adverse influence on hematological and biochemical parameters (Dedmari *et al*., 2014). Likewise SMFT, irrespective of their duration of application on the induced radial fracture site, had no adverse effect on physiological parameters, but showed a positive correlation with fracture healing clinical parameters (Dedmari *et al*., 2012). The majority of studies conducted on reproduction showed that there were no adverse effects. Pafkova (1992) found no higher incidence of mortality or malformation in chick embryos exposed to MF. It can be construed from the perusal of current available literature that there is no evidence of direct or acute toxic effects of SMFs generated by magnets on surrounding cells, except one study by Yagci and Kesim (2016), which found more micronuclei present with exposure to high density SMFs. The negative effects on in vitro cell cultures can be ascribed to the toxic effect of magnetic corrosion byproducts and not to SMFs (Lew *et al*., 2021).

Conflicting reports are recorded in the literature regarding the safety of prolonged exposure to the SMFT. In one study SMFT was reported not to produce any untoward long term or chronic adverse effects, excepting trivial symptoms such as vertigo and nausea in humans upon prolonged exposure to static magnetic flux densities upto 8T (Rongen *et al*., 2007). Many other studies reported adverse effects upon exposure to SMF for a prolonged period of time; increase in occurrence of lung and bladder cancer (Spinelli *et al*., 1991; Ronneberg and Andersen, 1995), brain tumors (Mur *et al*., 1987; Spinelli *et al*., 1991) and leukemia (Spinelli *et al*., 1991). However, current available evidence from epidemiological studies is not sufficient to draw any conclusions about potential health effects of static magnetic field exposure (Feychting, 2005). International Agency for Research on Cancer is also of same opinion that there is inadequate evidence in humans for the carcinogenicity of static or magnetic fields (IARC, 2002).

Constraints in Using Magnetic Materials

Peng *et al*., (2019), while exhaustively reviewing the role of magnetic materials in promoting bone regeneration felt the urgent need of highlighting various constraints coming in the way of magnetic materials to be used for healing purposes, especially as implants which are: i). Postoperative infection and rejection, ii). Interference of magnetic materials with some types of examination and treatment e.g., MRI, iii). Corrosion of the alloys used in magnetic materials, if not protected appropriately, which could otherwise prove toxic and make MFT unsafe, iv). local and systemic toxic effects of the alloys used in magnet synthesis, v). Wrong precedence of interpolation of the results obtained from animal models for human use, vi). Failure to ascertain the application of appropriate dosing and treatment parameters of magnetic materials that produce the optimal effects. Earlier Colbert *et al*., (2007), while reviewing the adoption of the 10 essential SMF treatment parameters reported, only site, frequency and duration of magnet application and magnetic support device are adequately described,other three essential treatment parameters specific to SMF dosing, i.e. identification of the target tissue, measurement of the SMF at the magnet's surface and estimation of distance of target tissue from the magnet, are either not described or only partially described in a preponderance of studies, and there is no mention of which pole configuration is applied or if the side of the magnet facing the skin was north, south or alternating polarity .

Peng *et al*., (2019) is also suggestive of combination of magnetism with light, sound, or heat, which may have a stronger effect on bone regeneration that magnetism alone. Further revelation is that a magnetic- material industry with the goals of low energy consumption, low environmental pollution, and low cost could be very important for treatment of bone defects in the future.

Conclusion

Literature reviewed reveals that magnetotherapy may be a potential complimentary option and seems to be an emerging state in veterinary sciences. *In vitro* and experimental *in vivo* studies show SMF is a booster for healing especially animal orthopaedic conditions. However, a very little work has been conducted on clinical trials in animals. Magnetic therapy in humans is well established and proven beneficial, efficacious, non-invasive and cheap complimentary therapy for various surgical and medicinal refractory conditions. However, there is currently lack of understanding in the cellular and molecular features induced by the magnetism. Further, the optimal MFT dosage and parameters like frequency, intensity and exposure time, remains to be established for each clinical condition.

Contribution by Authors

Equal contribution

Conflict of Interests

There is no conflict of interest.

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