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A REVIEW ON MAGNETOTATIC BACTERIA AND THEIR APPLICATIONS

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Abstract: Prokaryotic magnetotactic bacteria (MTBs) are widely distributed, motile and varied. They biomineralize an organelle known as the magnetosome. A nanoscale crystal of a magnetic iron mineral surrounded by a lipid bilayer membrane makes up a magnetosome. Magnetosomes are arranged in nearly all MTB cells as a well-ordered chain. The cell aligns and swims parallel to magnetic field lines, acting as a small, motile compass needle due to the presence of the magnetosome chain. MTB are present in almost all aquatic habitats and can contribute significantly to the biomass of bacteria in these types of environments. In MTB magnetosomes are arranged as a chain with in the cell in a linear direction as it swims, the cell passively aligns along magnetic field lines. Magnetotatic bacteria synthesis nano particles called magnetite and greigite which undergo biomineralization and it has special properties because of magnetosomes. These bacterial magnetite's are exploited for a variety of applications in medical sciences, biomedically, in biotechnology etc. applications like drug delivery, gene therapy, enzyme immobilization, hyperthermia, MRI etc., In this paper, we describe the general characteristics of MTB and their magnetic mineral inclusions, but focus is on the significance and applications of MTB and magnetosomes.

Index Terms **-** Magnetotatic bacteria, Magnetosomes, Biomineralization, Nanoparticles, Magnetic Field lines, Magnetite, Greigite.

INTRODUCTION

Magnetotatic bacteria (MTB) was first discovered in 1963 by Salvatore Billini. They are aquatic prokaryotes whose direction of motility is directed by the Earth's geomagnetic and externally applied magnetic fields (Bazylinski & Frankel 2004). These widespread microbes comprise a morphologically, phylogenetically, and biologically diverse group of Gram-negative bacteria that biomineralizes distinctive organelles called magnetosomes, which are in charge of the cells magnetotactic behavior or magnetotaxis (Blakemore 1975). These bacteria synthesize nano crystals of either magnetite (Fe_3O_4) or greigite (Fe_3S_4) and were termed as magnetosomes. The magnetosomes have a bilayer membrane made primarily of phospholipids that surrounds magnetic mineral crystals called magnetosomes, which are either magnetite (Fe_3O_4) or greigite (Fe_3S_4). The magnetosome membrane contain a number of proteins that are specific to MTB and are absent from the cytoplasmic and outer membranes (OMs) (Gorby et al., 1988). In MTB magnetosomes are arranged as a chain within the cell in a linear direction as it swims and the cell passively aligns along magnetic field lines (Frankel et al., 1997). Magnetosomes have a narrow size range approximately 35 to 120 nm (nano meter) where they have the most magnetic moment possible per unit volume (Bazylinski & Frankel 2004). When the magnet's polarity was switched, the bacteria's movement direction changed and they moved at a speed of approximately 100 µm/s in a geomagnetic field with a strength of approximately 0.5 Oe (Blakemore 1982). These bacteria were first observed in samples of marine sediments but extensive reports of MTB's occurrence have been obtained from freshwater, marine sediments, deep sea waters and other aquatic environments.

Morphologically, MTB are diverse including vibrions, rods, cocci, spirilla, and so-called "multicellular" organisms (Yan et al., 2012). Phylogenetically, MTB are related to the Nitrospiare phylum and the phyla Alpha, Delta, and Gamma proteobacteria (Lin et al., 2014). The culture of MTB required an extended period to isolate few MTB strains into a pure culture. Most of them are belong to the *Magnetospirillum* genus (Koziaeva et al., 2019). A wide range of MTB's found in natural samples are uncultivated and are rather studied by using microscopic and molecular biology techniques (Correa et al., 2020). In order to maintain the intracellular balance of ferric and ferrous iron, the process of magnetosome biomineralization necessitates maintaining the appropriate redox conditions and controlling the content of intracellular reactive oxygen species (Niu et al., 2020). These findings have recently been demonstrated to indicate that MTB can form an additional pool of iron in the cytoplasm outside of magnetosomes (Amor et al., 2020). This may let MTB survive in environments with low oxygen levels and high iron and other transition metal concentrations (Munoz et al., 2020). The possibilities of changing the chemical composition of magnetosome magnetite nanocrystals by replacing iron with foreign metal. This process of biomineralization provides a foundation for the development of novel methods for synthesizing nanomaterials (Prozorov et al., 2013) (Majidi et al., 2016) (Joshi et al., 2018) (Bain et al., 2019) (Van de walle et al., 2019). One such method is the biosynthesis of magnetite using human cells.

Bacteria that are magnetotactic are able to sense magnetic fields and can be externally steered, altered, and guided. To diagnose and treat cancer, they can also use magnet hyperthermia, magnetic resonance imaging, and drug delivery. Due to the rapidly rising need for nanoparticles in medicinal, biotechnology, and environmental protection, magnetotactic bacteria (MTB) have begun to be used for the production of magnetic nanoparticles (Kotakadi et al., 2022).

Biocompatible MTBs and BMs can be used as natural nanocarriers to precisely administer chemotherapy to the target site of the cancer cell. Traditional anticancer drugs, gene therapy, drug delivery, magnetic resonance imaging, detection assays, and treatments for hyperthermia can all be combined and altered in conjunction with MTBs and BMs. MTB and its magnetosomes provide several benefits, including high specificity separation, tissue specificity, reduced drug toxicity, and specific drug delivery. In this review paper, basic research on magnetotatic bacteria, magnetosomes and its production, components, its role and utility and also applications of MTB and magnetosomes are been explained clearly in a short form.

Morphology

Magnetotatic bacteria has morphological characters according to MTB species, morphology mostly shows its crystal shape, length, width in nanometers and number of magnetosomes present in the bacteria. The most commonly observed morphotypes in MTB are spherical or ovoid cells (cocci), rod-shaped (bacilli), and spiral bacteria of various dimensions as well as giant and multicellular. All of the MTB under study have cell walls that resemble those of Gram-negative bacteria and are motile through the use of flagella (Frankel & Bazylinski 2009). Some species have crystal shape like prismatic, cub octahedral, bullet-shaped etc. In the below following table 1 Some of the morphological characteristics are listed.

Table 1. Morphological characteristics of some MTB species depends on shape, size and average quantity of magnetosomes present (Gareev et al., 2021).

MTB Species	Crystal Shape	Average Crystal Length (nm)	Average Crystal Width (nm)	Average Magnetosomes Quantity
Magnetospirillum magneticum AMB-1	prismatic, cuboctahedral	30–50		15–20
Magnetococcales spp.	prismatic, cuboctahedral	70–250	40–200	10–200
Magnetovibrio blakemorei MV-1	prismatic	50–60	35–40	2–20
Magnetospirillum gryphiswaldense MSR-1	cuboctahedral	30–50		15–40
Desulfovibrio magneticus RS-1	bullet-shaped	40–70	20–40	<10
Nitrospirota bacterium MYR-1	bullet-shaped	40–45	80–180	up to 1000
Ca. Magnetobacterium bavaricum TM-1	bullet-shaped	35–40	100–120	

Magnetosomes

MTB synthesizes magnetosomes which are nano-sized magnetic iron minerals, inside cells. The magnetosome membrane, a lipid bilayer, envelops this bacterial nanoparticle (Gorby et al., 1988). Magnetosomes made up of both organic and inorganic essential magnetosomes membrane in which inorganic magnetosome is either magnetite (Fe_3O_4) or greigite (Fe_3S_4). In MTB the bacterial cell's magnetic dipole moment is increased when the magnetosomes are arranged in a single chain. Vesicles originating from the inner membrane of the magnetosome have produced the organic phase of the structure (Gorby et al., 1988). Magnetosomes undergo biomineralization process through this process, the production of the inorganic magnetite core and organic magnetosome membrane is highly regulated genetically.

According to D.A. Bazylinski 1994 the morphology of magnetosomes like crystal structure and size can be identified and studied commonly by using Transmission electron microscopy (TEM) or High-resolution transmission electron microscopy (HRTEM) (Bazylinski et al., 1994), Crystal structures like cubo-octahedral, bullet-shaped, elongated prismatic and rectangular morphologies (Bazylinski et al., 1994). Many studies shows that magnetosomes are intracellular organelle made up of a magnetic iron mineral single-magnetic domain crystal enclosed in a lipid bilayer membrane containing certain proteins (Schaechter 2009). The production of magnetosome is observed in various evolutionary lineages of Gram-negative bacteria such as the Nitro Spira phylum, Gamma proteobacteria, Deltaproteobacteria and Alpha proteobacteria (Bazylinski et al., 1994). Typically, the stable, single magnetic domain range of 30 to 120 nm is inhabited by inorganic ferromagnetic crystals of either monocrystalline magnetite (Fe_3O_4) or the iron sulfide greigite (Fe_3S_4) which constitute all magnetosome particles. A range of consistent species-specific shapes, largely unidentified in inorganic systems, can be detected by magnetosome crystals (Bazylinski et al., 1994) (Figure 1).

Magnetosomes are extracted from cultured species are *Magnetospirillum magnetotacticum* strain MS-1, *M. gryphiswaldense* MSR-1, and *M. magneticum* strain AMB-1(Matsunaga et al., 2005), pure culture of magnetosomes is extracted from this species. The main purpose of magnetosome is a type of cell that swims and aligns itself parallel to lines of magnetic field. Because of the magnetosome chain, it can move like a little compass needle (Keim et al., 2004). The biological qualities of magnetosomes paired with proteins, glycoproteins, functional proteins/enzymes and other substances make them suitable for a variety of uses in genetic research (Jacob & Suthindhiran 2016). The magnetosomes gene cluster (MGC), formerly known as the magnetosomes island or MAI, control the synthesis of magnetosomes. The MGC is a home to genes that regulate the morphology, chemical makeup and production of magnetosomes. Only MTB is linked to distinct MGCs. Magnetosome membrane (or mam) genes are those required for the biomineralization process. There are nine that are found in every MGC: mamA, -B, -K, -P, -Q, -E, -O, and -I. It's possible that horizontal gene transfer (HGT) will spread the magnetosome genomic islands to other bacteria (Uzun et al., 2020).

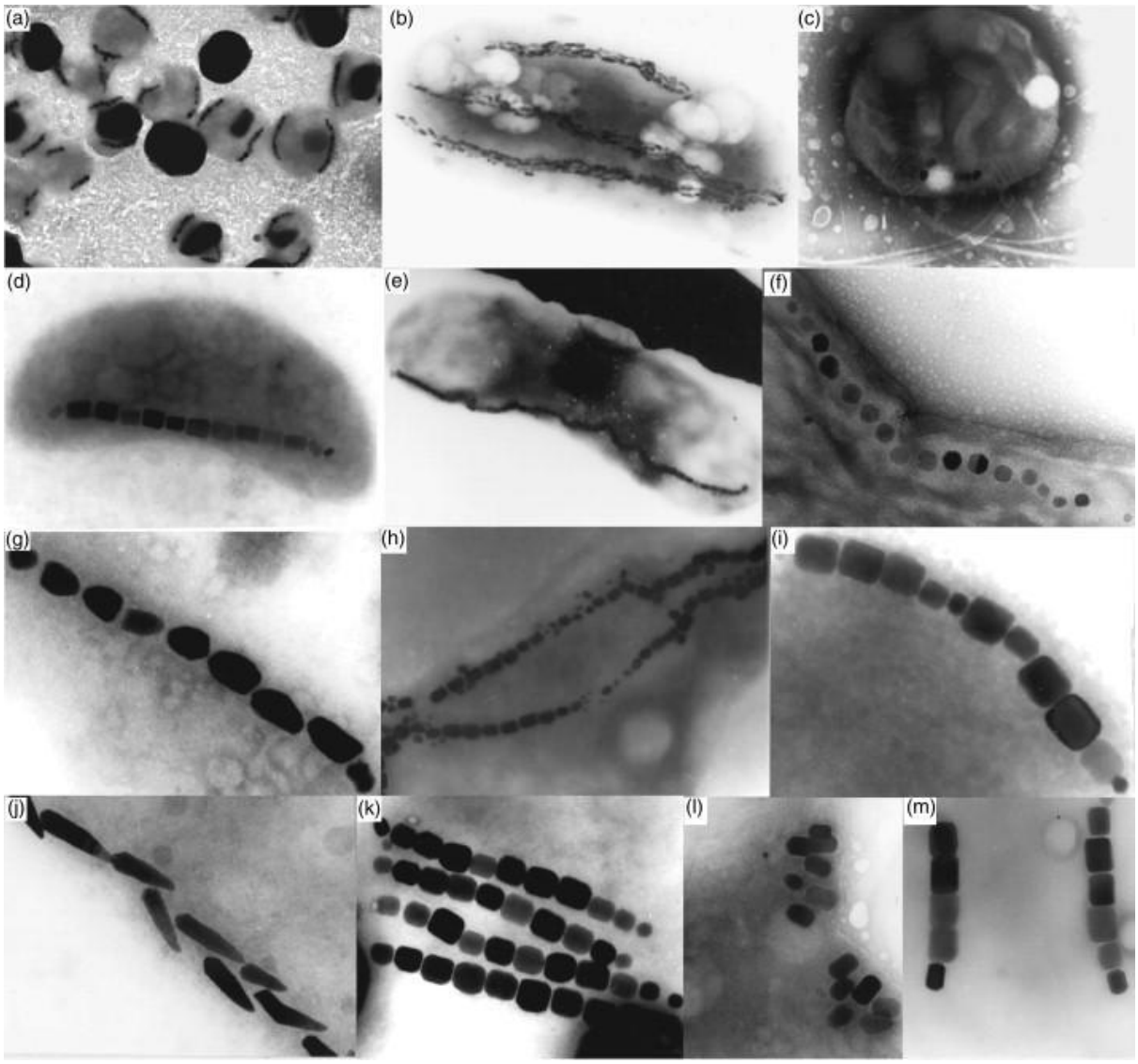

Figure 1: Variation of magnetosomes and magnetotactic bacteria (MTB). (A-E) Transmission electron micrographs of a range of morphological shapes identified in MTB: giant rod-shaped bacteria with one or more magnetosome chains (b, e), magnetic Vibrio (d), and coccoid cell morphologies (a, c). (f–m) Electron micrographs of the magnetosome arrangement and crystal morphologies discovered in different MTB. (Micrographs by Gruska M and Plitzko ((2006) Magnetosomes of magnetotactic bacteria. In: Shively JM (ed.) *Microbiology Monographs* 2 *Complex Intracellular Structures in Prokaryotes*, pp. 167–192).

Magnetotaxis

The term "magnetotaxis" refers to the ability of a cell with a chain-like arrangement of magnetosomes to orient and move along geomagnetic field lines by imparting a magnetic dipole moment to the cell. In stratified aquatic environments, including freshwater and marine sediments, magnetotaxis is hypothesized to help the cell discover and maintain an optimal position inside vertical chemical gradients in conjunction with chemotaxis, aerotaxis and even phototaxis (Schaechter 2009). Since magnetotactic bacteria, in contrast to other bacteria use geomagnetic field lines as a fixed reference to swim, magnetotaxis is thought to be favorable to bacteria in vertical chemical concentration gradients (such as oxygen) in locating and maintaining an optimal position in the gradient (Linus & Bazylinski 2009). Because the geomagnetic field is inclined downward from horizontal in the northern hemisphere and upward in the southern hemisphere, bacteria that are looking north in the northern hemisphere and cells that are looking south in the southern hemisphere would move along the inclined geomagnetic field lines and migrate downward toward the bottom of natural waters (Blakemore 1975). This theory is reinforced by the fact that South-seeking MTB is more common in the Southern hemisphere and North-seeking microorganisms are more common in the Northern hemisphere, and both polarities are equally abundant in the equator, where there is no inclination (Blakemore 1975) (Frankel & Blakemore et al., 1981).

The model that was shown by Richard Frankle is valid when performing a microscopic analysis in the hanging drop test. It was shown that exposure to lowering circumstances might cause the magnetic coccus MC-1 cells' natural North-seeking swimming direction to revert to "South-seeking," and that exposure to light with short wavelengths (less than 500 nm) could cause the cells to return to their original North-seeking direction. This resulted in the development of Feinberg's improved models of "axial magneto-aerotaxis," in which the organisms sense the field's axis, and "polar magneto-aerotaxis," in which the cells sense the field's direction (Schuler & Baeuerlein 1998). A two-state sensory mechanism known as "polar magneto-aerotaxis" was hypothesized to perceive the direction of swimming and, in turn, the sense of flotillar rotation in response to an upper and lower oxygen concentration threshold. The applicability of this elaborate model to other MTB is yet unknown; so far, it has only been empirically validated for the magnetic coccus MC-1. The cultivated strains of Magneto spirillum exhibit "axial magneto-aerotaxis" in their cells, which differs from the previously discussed "polar magneto-aerotaxis" in that individual cells do not exhibit a preferred North- or South-seeking polarity, but rather can align along magnetic field lines (Schuler, Spring & Bazylinski 1999) (Flies et al., 2005).

Magnetite

Bacteria use the net magnetic moment from the magnetite crystals to move in a direction determined by the local magnetic field, a process known as magnetotaxis. Numerous magnetotactic bacteria have restricted, particular redox conditions that they preferentially thrive in. On scales ranging from millimeters to meters, redox gradients can be found (Kopp & Kirschvink 2008). The main component of magnetite is iron oxide, which has equal proportions of iron II and iron III. Iron (II, III) oxide is a common expression for it, and its empirical formula is Fe_3O_4. It was also known as tri-iron tetraoxide and ferrous-ferric oxide in the past. The main application of magnetite is as a vital iron ore for the production of steel. Additional uses include magnetic micro- and nanoparticles for a range of materials and processes, paint and ceramic pigment, and catalyst in the Haber process for ammonia production (Hasany et al., 2013).

Greigite

Magnetosomes containing iron sulfide crystals are produced by numerous marine magnetotactic organisms. In MB, there are two types of iron sulfide minerals: greigite or a combination of greigite and temporary nonmagnetic phases of iron sulfide that most likely originated from greigite (Posfai et al., 1998)). The size range of the magnetite and greigite crystals in MB is comparable, and the single-domain rule is appropriate (Brazylinski & Frankel et al., 2000) (Brazylinski & Frankel et al., 2000). Although one species has greigite crystals with various kinds of morphologies, such as pleomorphic, pseudo rectangular prismatic, tooth-shaped, and cubooctahedral, the morphologies of the greigite particles in the rod-shaped bacteria also appear to be species- and/or strain-specific (Brazylinski & Frankel et al., 2000).

Applications of MTB and Magnetosomes

The development and exploration of bacterial magnetosomes for many applications has been based on their unique characteristics, including membrane-bound structure, dispersal ability, nanoscale size, limited size distribution, and ferrimagnetism. Magnetic fields have the ability to control the immobilization of sizable amounts of bioactive compounds through the usage of bacterial magnetite magnetosomes.

A number of applications have been considered for MTB and their magnetosomes as biotechnological instruments, as was previously stated. The research that used these magnetosomes will be briefly described here. Bioremediation, cell separation, DNA/antigen recovery or detection, drug delivery, enzyme immobilization, magnetic hyperthermia, and contrast enhancement of magnetic resonance imaging are among the applications that use magnetite-producing MTB, magnetite magnetosomes, and or magnetosome magnetite crystals (Vargas et al., 2018).

1. Drug delivery

In the fields of biomedicine and nanotechnology, one of the most researched applications of magnetic nanoparticles is the use of it as a tool for drug and gene delivery systems (Sun et al., 2011). The utilization of magnetosomes for this purpose is the subject of several research articles which are summarized here.
Drugs like doxorubicin can be conjugated to the magnetosome surface due to the presence of different chemical groups on the magnetosome surface (Sun et al., 2007) (Sun et al., 2008). Doxorubicin-conjugated magnetosomes have been investigated as liver cancer anti-tumor therapies. Research indicates that conjugating doxorubicin to the magnetosomes can moderately enhance its anti-tumor effect which was 79% for doxorubicin on its own and 87% for doxorubicin linked to the magnetosomes (Sun et al., 2007) (Sun et al., 2008).

Advantages
The reduction in toxicity is the primary benefit of employing magnetosomes. When doxorubicin is administered alone, its mortality rate is 80%, making it extremely dangerous. However, when doxorubicin is coupled to magnetosomes, its mortality rate is 20% (Sun et al., 2007) (Sun et al., 2008). Consequently, when doxorubicin is conjugated to the magnetosomes, the benefit to risk ratio increases significantly, indicating the promise of medicines conjugated to magnetosomes for cancer treatments.

Disadvantages
Possibly immune-stimulating because to external LPS (Felfoul et al., 2016). Potential change in activity; unclear biological destiny; requirement for endotoxin test (Wang et al., 2018).

2. Cell separation

Applications and conditions for magnetic cell separation vary considerably and include basic biological research, environmental monitoring, disease diagnosis, and etc. It is a significant step in numerous distinct biosensor assessments, and a lot of research has been directed into generating multifunctional magnetic nanoparticles with fluorescent (Cui et al.,2019) (Pramanik et al., 2016) (Martynenko et al.,2019) (Poncelet et al., 2021) electrochemical (Chen et al., 2019) (Dou et al., 2019), or plasmonic (Wilson et al.,2020) (Takahashi et al., 2017) properties in order to ease both magnetic capture and downstream detection. This research extends into developing new cell separation systems.

Advantages
Reusing the capture complex, separation with high specificity (Ceyhan et al., 2006).

Disadvantages
Cloning and Expression processes that are challenging; Variations in cell viability following capture (Ceyhan et al., 2006).

3. DNA/Antigen recovery or detection

In protein detection techniques, magnetosomes have proven to be effective (Ceyhan et al.,2006). Magnetosomes were coupled to the protein streptavidin by means of biotin groups that were attached to the membrane of the magnetosome. Largely functional biomolecules such as biotinylated DNA oligonucleotides and biotinylated antibodies could be linked together with the help of these semisynthetic composite particles that bind biotin (Ceyhan et al.,2006). This method could have a significant impact on proteome research and immunological diagnostics (Lin et al.,2010). Using antibody-functionalized magnetosomes in a surface-independent immunoassay, a variant of an automatable, extremely sensitive immuno-PCR (M-IPCR) was developed (Wacker et al.,). Hepatitis B antigen (HBsAg) in human serum was immobilized using antibody-functionalized magnetosomes in this technique, which also involved increasing the signal produced by the detecting complex through magnetic concentration (Wacker et al.,). In several immunoassays involving allergen detection, cancer cell identification, and immunoglobulin quantification, antibodies coupled to magnetosomes or magnetosome crystals have been generated and have shown beneficial (Leao et al.,). Measurements of the change in light scattering produced by cell alignment in a magnetic field or the change in absorbance brought about by bacteria swimming across the light beam were made possible by the use of magnetic fields. It was discovered that Micro spectrophotometry (MSP) is an effective method for measuring the magnetism of bacteria and examining how magnetotactic bacteria align and swim in magnetic fields (Lefevre et al.,2009).

Advantages
High sensitivity and recovery efficiency (Ceyhan et al.,2006).

Disadvantages
Complex Technology (Ceyhan et al., 2006) (Wacker et al.,2007).

4. Enzyme immobilization

Catalytic units can be expressed by using magnetosomes' protein display technique. They are therefore ideal choices for sustaining immobilized enzymes. Due to their ease of recovery, magnetic nanoparticles, such as magnetosomes, have been frequently exploited as support materials for enzyme immobilization (Johnson et al.,2011). A multi-enzyme complex was produced using magnetosomes, and peptides were genetically connected to MamC via peptide bridges. The beta-oxidase or endoglucanase enzymes were subsequently bound to the complex by means of these peptides. When the non-immobilized enzymes were evaluated separately, their cellulose-degrading activity was significantly lower than that of the complex. 70% of the multi enzymatic compound's cellulose-degrading activity remained visible after five cycles of usage (Ginet et al.,2011).

Advantages
Nano biocatalyst reusing; immobilizing many catalysts (Ginet et al.,2011).

Disadvantages
Challenging cloning and expression processes; potential immobilization-related activity loss (Ginet et al.,2011) (Honda et al., 2015).

5. Hyperthermia

More importantly, magnetosomes are promising candidates for magnetic hyperthermia-based cancer treatment. An alternating magnetic field is used to heat magnetic nanoparticles that have been applied (or delivered) to tumours in order to induce magnetic hyperthermia. There is antitumor activity due to the heat. Therefore, the nanoparticles must generate a lot of heat in order to be effective for magnetic hyperthermia. Large diameters, ferromagnetic behavior at physiological temperature, and high levels of crystallinity are the main reasons why the magnetosomes have superior heating properties. Treatment for hyperthermia may be beneficial for cancer patients. Compared to chemotherapy and radiation therapy, it is less restrictive, has no dangerous side effects, and can even be combined to increase the effectiveness of treatment (Johannsen et al., 2007). The hyperthermia treatment involves raising the tumor's temperature, usually between 37 and 45 °C, in order to kill tumor cells and either diminish or eradicate the tumor entirely (Cheng et al.,2016) (Alphandery et al., 2017) (Alphandery et al., 2011) (Alphandery et al.,2017) (Lee et al.,2015) (Mathuriya et al., 2016) (Alphandery et al., 2013) (Alphandery et al., 2012)). Superparamagnetic iron oxide nanoparticles (SION) are synthetic nanoparticles used to treat hyperthermia; however, their efficacy is frequently restricted due to their inability to be placed selectively and precisely within the targeted tumor tissue (Moroz et al., 2002).

Through the delivery of magnetic nanoparticles to the tumor site and the generation of heat in response to an applied alternating magnetic field (AMF), magnetically-induced hyperthermia causes cell death. To reach deep enough into the tumor, the administered AMF's frequency might vary from a few kilohertz to 10 MHz. Magnetothermal therapy has been used in the past few years to treat glioblastoma and breast cancer, among other tumor forms (Alphandery et al., 2011) (Alphandery et al., 2017).

Advantages
Less severe adverse effects compared to radiation and chemotherapy; tissue specificity. Possibly utilized as a diagnostic instrument (Alphandery et al., 2017) (Alphandery et al., 2011) (Mannucci et al., 2018).

Disadvantage
Unclear biological fate; Endotoxin test needed (Alphandery et al., 2017) (Alphandery et al., 2011) (Mannucci et al., 2018).

6. MRI (Magnetic Resonance Imaging)

To identify and assess malignancies, MRI is frequently employed. This radiologic study employs the bacteria Magneto spirillum. With microaerophilic properties, it is a magnetic microorganism. Enclosed by a bilayer membrane, it consists primarily of magnetosomes made of magnetite (Araujo et al.,2015). Magnetosomes have been experimentally demonstrated to have potential applications as MRI image contrast agents in a number of cell models, including pancreatic cells (Lee et al., 2011), brain cells (Orlando et al., 2016) (Boucher et al., 2017), mammalian cells (Vargas et al., 2018), xenograft tumor cells (Boucher et al., 2017) (Xiang et al.,2017), and breast cancer cells (Xiang et al.,2017). Magnetosomes have shown to be extremely promising implements for tumor identification and hyperthermia-based treatment in practically every instance.

A multimodal approach was used to evaluate the biological properties of magnetic nanoparticles (MNPs) made from magnetotactic bacteria. Temperature increases were seen when magnetosomes (MN) were exposed to an alternating magnetic field (AMF). Additionally, when evaluated in samples with increasing concentrations of MN, the temperature increase showed a strong linear relationship. When injected directly into living tissue, chains of MNs are highly recognizable in vivo by MRI due to their concentration of iron. This implies that these nanoparticles might be applied as a magnetic tracer or a negative contrast agent (Mannucci et al.,2014).

Advantages
Used as therapeutic tool (by hyperthermia, drug delivery); High affinity to target cells; High detection sensitivity (Lee et al., 2011) (Orlando et al., 2016) (Boucher et al., 2017) (Vargas et al., 2018) (Xiang et al., 2017).

Disadvantages
Unclear biological fate; Endotoxin test needed (Lee et al., 2011) (Orlando et al., 2016) (Boucher et al., 2017) (Vargas et al., 2018) (Xiang et al., 2017).

Conclusion

Several studies and researches on magnetotatic bacteria and magnetosomes stated that this MTB is very essential bacteria is applicable in many biomedical, therapeutic, drug delivery, gene therapy, hyperthermia etc. Magnetotatic bacteria as magnetic properties and produce magnetosomes and synthesize nano particles called magnetite and gretite in which iron-oxides are present. These magnetosome cells arranged in a linear direction which swims along magnetic fields lines towards earth magnetic fields. In morphology, the size, shape of MTB is varied according to the different types of species. These magnetosomes has a capability to eradicate tumor cells by producing iron-oxide compounds which produce more heat, many researches and practices have done on this. Not only this, MTB and magnetosomes have numerous applications. Additionally, there is a lot of promise in this sector for magnetotactic bacteria and their unique organelles, called magnetosomes, which contain ferromagnetic crystals. Advances in comprehending magnetosome magnetite biomineralization and devising diverse techniques for their functionalization have

substantially amplified the prospects of magnetosomes in several supplementary uses. Because MTBs and BMs are biocompatible, they can be used as natural nanocarriers to precisely administer chemotherapy to the target site of cancer cells. Traditional anticancer drugs, gene therapy, drug delivery, magnetic resonance imaging, detection assays and treatment for hyperthermia can all be combined and altered in conjunction with MTBs and BMs. MTB and its magnetosomes provide several benefits, including as high specificity separation, tissue specificity, reduced drug toxicity, and specific drug delivery. These bacteria are manipulable in a magnetic field due to their ferromagnetic properties. This present numerous chances for the creation of structures, which are integral to the targeted cancer therapy approach. Therefore, it is now very clear that MTB have not only been shown to have a significant impact in environmental biogeochemistry but also in applied biotechnology, nanotechnology and medicine.

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