Journal for Research in Applied Sciences and Biotechnology

www.jrasb.com

ISSN: 2583-4053

Volume-3 Issue-2 || April 2024 || PP. 242-251

https://doi.org/10.55544/jrasb.3.2.41

Hydrogel-Based Drug Delivery Nanosystems for the Treatment of Brain Tumors: A Systematic Review

Subham Kumar[1], Puja Kumari[2], Dilip Suthar[3], Rajeev Ranjan Raj[4] and Aniket Jain[5]

[1]Assistant Professor, School of Pharmacy and Research, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, 248007, INDIA

[2]Assistant Professor, SNS College of Pharmacy, Motihari, Bihar, 845401, INDIA

[3]Research Scholar, School of Pharmaceutical Sciences, Jaipur National University, Jaipur, Rajasthan, 303017, INDIA

[4]Research Scholar, School of Pharmaceutical Sciences, Jaipur National University, Jaipur, Rajasthan, 303017, INDIA

[5]Research Scholar, School of Pharmaceutical Sciences, Jaipur National University, Jaipur, Rajasthan, 303017, INDIA

[1]Corresponding Author: subhamk.vajji997@gmail.com

www.jrasb.com || Vol. 3 No. 2 (2024): April Issue

Received: 21-04-2024	**Revised:** 26-04-2024	**Accepted:** 09-05-2024

ABSTRACT

The limitations and negative effects of current therapeutic techniques for brain tumors necessitate the selection of alternative therapeutic options. Therapeutic hydrogel systems that are monitored by magnetic resonance imaging (MRI) are one alternative for neurosurgical treatment of brain tumors that does not need any invasive procedures. There is a significant deal of potential for the treatment of brain tumors that can be attributed to the specific physical and chemical properties that hydrogels possess. The ability to encapsulate therapeutic molecules, provide regulated and sustained drug release, and successfully pass the blood-brain barrier are some of the properties that are included in this category. By combining hydrogel systems with magnetic resonance imaging (MRI) capabilities, it is possible to design therapeutic approaches that provide regulated release of therapeutic medications and real-time monitoring possibilities. Despite the fact that surgical resection is still extremely important, there is a growing demand for alternatives that can supplement or even replace it. Within the scope of this narrative review, the therapeutic hydrogel systems that are monitored by magnetic resonance imaging (MRI) will be evaluated to determine their potential for the non-surgical treatment of brain tumors.

Keywords: Hydrogel, brain tumor, MRI, therapeutic effects.

I. INTRODUCTION

When it comes to the treatment of brain tumors, hydrogel systems have emerged as particularly advantageous possibilities[1]. These hydrophilic polymers are capable of forming complex three-dimensional structures that exhibit unique physical and chemical properties, particularly with regard to the process of cross-linking. As a consequence of this, they perform exceptionally well in applications involving the administration of drugs, tissue engineering, and regenerative medicine. Hydrogels have the capability of being created in a manner that enables them to contain therapeutic chemicals and distribute pharmaceuticals in a manner that is both regulated and prolonged, and this can be done exactly at the location of a tumors[2]. In addition, the biocompatibility and adaptability of these materials make it possible to perform modification in order to meet specific requirements in the treatment of brain tumors. In addition to this, it was shown that hydrogel is a more effective alternative to conventional chemotherapy. In order to determine whether or not therapeutic hydrogel systems that are monitored by magnetic resonance imaging (MRI) could be used to treat brain tumors without the need for surgical intervention, a comprehensive narrative evaluation was conducted. High-resolution anatomical and functional features can be

ISSN: 2583-4053

Volume-3 Issue-2 || April 2024 || PP. 242-251

https://doi.org/10.55544/jrasb.3.2.41

obtained through the use of magnetic resonance imaging (MRI), which offers improved imaging capabilities that allow for reliable monitoring of cancer progression and response to treatment[3]. When hydrogel systems are combined with magnetic resonance imaging (MRI) techniques, it becomes possible to develop therapeutic strategies that not only allow for the noninvasive evaluation of treatment outcomes but also provide immediate monitoring and regulated delivery of therapeutic medications.

Thanks to the creation of a drug delivery system that was specifically created for the goal of delivering drugs to brain tumors, hydrogels have emerged as a novel and cutting-edge therapy technique that has the potential to effectively administer pharmaceuticals to brain tumors. Hydrogels are networks of polymers that are generated by hydrophilic polymer chains that cross-link with one another[4][5]. This results in a structure that resembles a biological system when it is placed in a solution that is based on water. Following the formation of covalent bonds between the polymeric chains, these compounds are capable of absorbing water, but they do not dissolve in water or any other solution. In order to develop a drug delivery system that is both efficient and risk-free, hydrogels are dependent on certain properties. These traits include the ability to decompose in a natural manner and compatibility with living organisms. Considering that hydrogels are in close touch with biological cells and tissues over an extended period of time, this is a crucial consideration[6]. The formulations of hydrogen are classified according to the origin of their derivatives (natural, synthetic, and semi-synthetic), the structure of the polymers that are utilized, the duration of the formulations, the chemical features of the formulations, and the electrical charge of the network that they are composed of. The quantity in question 5. Biopolymers can be classified as either natural or synthetic, depending on the derivative material from which they are formed. These biopolymers are utilized for medical and drug delivery purposes. The mechanical properties of natural polymers are inadequate, despite the fact that they have superior biodegradability and compatibility with the tissues of the body. Depending on the formulations of hydrogel and biopolymer, natural polymers can be divided into two distinct categories[7]. Collagen, gelatin, polypeptides, and DNA are examples of substances that fall into the first group of protein-based polymers. Hyaluronic acid (HA), chitosan, fibrin, and alginate are all examples of polymers that fall within the second category, which is comprised of polysaccharide-based polymers. Polycaprolactone (PCL), poly vinyl alcohol (PVC), and polyethylene glycol (PEG) are the three major components that are frequently found in synthetic formulations. The mechanical properties of these synthetic biopolymers are better to those of natural polymers; yet their compatibility with host tissue is limited.

Hydrogels are characterized by their mechanical, swelling, and biological properties, all of which are essential for their use in tissue engineering and drug delivery systems (DDS).7.8 The swelling characteristic of hydrogel could be attributed to its three-dimensional cross-linking polymer structure, which is responsible for the material's capacity to absorb and hold water. One of the properties that is responsible for changing medicine release and regulation is the swelling property[8]. The outcome is dependent on exogenous factors including pH, temperature, and ion concentration, among other things. For applications in the field of biomedicine, the biomechanical properties of hydrogel are absolutely essential. Certain characteristics of the polymer, such as its viscoelasticity, tensile strength, and stiffness, are responsible for determining the architecture of the polymer and the release of therapeutic medicine with a prolonged duration[9][10].

Biodegradability refers to the ability of a substance to be broken down by natural processes; biocompatibility refers to the ability of a substance to interact well with living tissues; non-toxicity refers to the absence of harmful effects on living organisms; and low immunogenicity refers to the low likelihood of causing an immune response.8.9 Due to the invasive nature of brain tumors, such as glioblastoma, the removal of these tumors through surgical means and the response to the various chemotherapy medicines might be difficult. It is necessary for the therapeutic medicine to be able to successfully pass through the blood-brain barrier in order for it to be effective in treating brain tumors. Because of their injectability, structure, and ability to encapsulate the therapeutic agent, hydrogel systems are able to effectively transport chemotherapeutic drugs to the precise site of neoplastic cells[11].

This is made possible by the capacity of hydrogel systems to encapsulate the therapeutic agent. Because of the hydrogel's swelling and degradable properties, this leads to a reduction in the drug's toxicity and an improvement in its ability to penetrate the body. Due to the fact that the drug and hydrogel systems are incompatible with one another, it is necessary to incorporate nanoparticles into hydrogels in order to get the best possible drug administration possible[12]. Because of the hydrogel's affinity for water and the medications' dislike to water, drug delivery is made more difficult by these two factors. By efficiently encapsulating the drug within its structure and demonstrating compatibility with hydrogel materials, nanogel is able to overcome this constraint. This combination is exceptionally important because it helps to regulate the flow of drugs. Nanogels provide a number of advantages, such as the distribution of medications in a targeted manner, the regulated release of pharmaceuticals, the provision of responsive pharmacological therapy, and detoxification. Additionally, nanogels have the ability to lessen the movement of cancer cells from the cortex into

Journal for Research in Applied Sciences and Biotechnology

www.jrasb.com

ISSN: 2583-4053

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the hydrogel system that contains chemotherapy and other medications.3, 10, and 11 are the numbers in question. In addition, hydrogel systems have the capacity to detect the areas of cancer by adding radioisotopes and to provide radiation in an effective manner[13]. Ten and eleven are the numerals. Excision through surgery, chemotherapy, and radiation therapy are the most prevalent methods of treatment for brain tumors. A group of researchers led by Bastiancich developed lipid-based nanoparticles that were encased in a hydrogel and contained pharmaceutical[14]. These nanoparticles were able to diminish the size of cancer cells and demonstrated higher efficacy when compared to the drug themselves. By collecting cancer cells, a different type of hydrogel technology, which is referred to as cancer cell sticky (CSH) hydrogel, contributes to the reduction of invasive capabilities13. Polymeric micelles, magnetic nanoparticles, alginate nanogels containing gold particles, and microspheres are some of the other hydrogel systems that are utilized for the treatment of brain tumors[15]. The process of administering hydrogel, which contains a therapeutic medicine, to treat brain tumors is illustrated in Figure 1, which provides a concise summary of the technique.

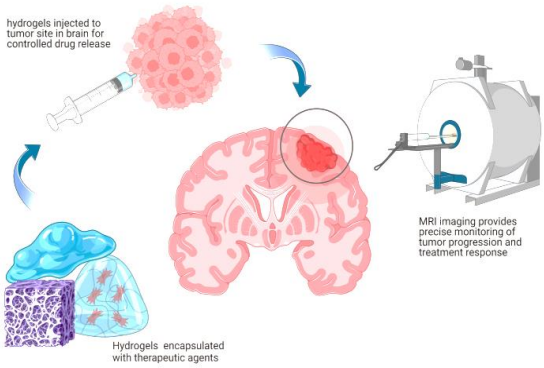

Fig. 1 shows how therapeutic drugs are applied using hydrogel to treat brain tumours.

II. ROLE OF HYDROGELS IN TREATING DIFFERENT TYPES OF TUMORS

Hydrogels offer a number of remarkable characteristics, including biocompatibility, biodegradability, the capacity to load pharmaceuticals, and the ability to manage the release of prescription drugs. Radiotherapy, chemotherapy, immunotherapy, hyperthermia, photodynamic therapy, and photothermal therapy are only few of the cancer treatments that make substantial use of these substances[17].

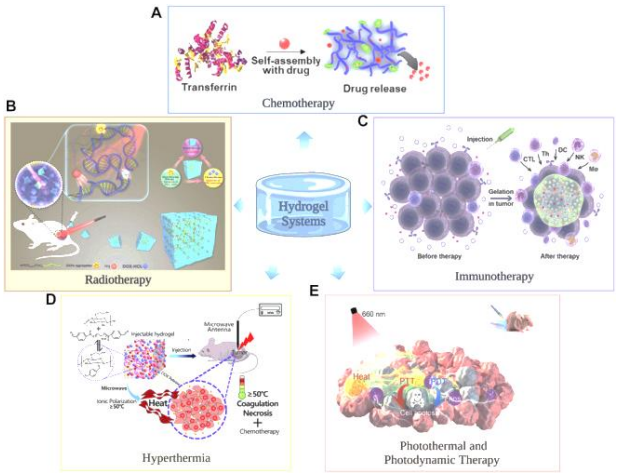

Fig. 2: Hydrogels have the potential to be utilised in a variety of cancer treatments, including chemotherapy (A), radiation (B), immunotherapy (C), hyperthermia (D), photodynamic therapy (E), and electrothermal therapy (E). A) This work was reproduced with the author's permission (Lee et al., 2021). John Wiley and his sons, copyright 2021 all rights reserved. (B) GNPs, doxorubicin, and radiation-like iodine-131 tagged methoxy polyethylene glycol (mPEG) are the components that make up the hydrogel. This hydrogel is utilised in the treatment of cancer through irradiation.

Chemotherapy

A German scientist named Paul Ehrlich was a pioneer in the creation of chemotherapy procedures for the treatment of infectious diseases. These techniques were developed around the beginning of the twentieth century. At the same time, he made the discovery that chemotherapy drugs have the potential to treat cancer by conducting experiments on animal models before making the discovery. The progress of conventional chemotherapy strategies for treating a variety of cancers was made possible as a direct outcome of these ground-breaking discoveries [18]. It is possible to attain systemic doses of chemotherapy medicines through oral administration, intramuscular administration, or intravenous administration. Unfortunately, they do not possess a distinct antitumor impact. This means that they not only inhibit the excessive growth of malignant cells, but they also reduce the growth of normal cells that have a high rate of proliferation. These normal cells include hair follicles, the epithelium of the digestive tract, and bone marrow stem cells. In addition to causing major adverse effects, this also causes damage to normal cells and tissues. As a consequence of this, it is not recommended to administer them regularly, and it is exceptionally important to evaluate the risk-to-benefit ratio of these medications. It is possible to determine the best dosage of chemotherapeutic medications by taking into consideration components such as the quantity of

ISSN: 2583-4053

Volume-3 Issue-2 || April 2024 || PP. 242-251

https://doi.org/10.55544/jrasb.3.2.41

particular tumors cells, the level of resistance to treatment, and the information regarding the toxicity of the drug. In the end, the success of chemotherapy drugs is measured by determining the number of cancer cells that are still present and by monitoring any adverse effects that may arise [12–15].

Chemotherapy drugs destroy tumor cells by various mechanisms, including: (1) provoking internal and external apoptosis pathways through increasing Fas ligand (FasL) expression and consequently cytochrome C release; (2) inducing cell cycle arrest through activation of p53 gene following DNA damage and inhibition of kinases; (3) increasing autophagy pathway through signaling of the phosphatidylinositol 3-kinases/ mammalian target of rapamycin (PI3K/mTOR) and mitogen-activated protein kinase (MAPK); (4) alkylation of DNA and causing a single- or double-strand break in DNA that finally leads to cell death; (5) preventing DNA or RNA synthesis due to having a similar structure with nucleotides named antimetabolites that have higher activity in S phase of cell cycle; (6) interference with microtubules resulting in cell growth cessation; (7) causing direct or indirect DNA damages through production of reactive oxygen species (ROS); and (8) inhibition of topoisomerases and stopping cell proliferation. The vast majority of these activities lead to oxidative stress and the activation of the repair response that is associated with ataxia-telangiectasia mutated/ATM and Rad3-related (ATM/ATR). This response involves the activation of p53 and its subordinate protein p21, which can result in either a stoppage of the cell cycle or an acceleration of the senescence process [16–27].

Immunotherapy

But Adoptive cell therapy (ACT) is a promising method that use the patient's immune system to combat aga. The adaptive immune system and the innate immune system both have significant roles in the immune response to malignancies [9, 10]. B cells, CD8+ cytotoxic T cells (often referred to as CTLs), and CD4+ helper T cells are recognized as constituents of the adaptive immune system [28]. The innate immune system can regulate the adaptive immune system by secreting several signals that activate both T and B cells (12). Antigen-presenting cells (APCs) are responsible for identifying external antigens in the body and facilitating communication between different systems [29]. Research [30] has firmly demonstrated that cytotoxic T lymphocytes (CTLs) play a crucial role in the immunological response to cancer. After being cross-primed by professional antigen-presenting cells (pAPC), initially naïve cytotoxic T lymphocytes (CTLs) commence a series of events that ultimately result in the killing of cancer cells by CTLs. This assault can be initiated by granzymes or perforin, or it can be initiated by ligands from the tumors necrosis factor (TNF) superfamily simultaneously [31]. The activation of the anti-tumor action can also occur through the stimulation of specific antigens or co-stimulation signals to cytotoxic T lymphocytes (CTLs), resulting in the subsequent production of tumors necrosis factor-alpha (TNF-α) and interferon gamma (IFN-ɑz) [32]. This occurs in parallel with the impact stated above. Adoptive cell therapy (ACT), in reality, is a highly promising method. Immunotherapy entails the deliberate alteration of the patient's immune system to effectively target and eliminate cancerous cells or tumors. As an illustration, natural killer cells (NK cells) have the capacity to adhere to cancer cells. This method has been employed in the creation of several strategies for anticancer therapy (ACT). Several methods used in this context are natural killer cell therapy (NK cells), tumor-infiltrating lymphocyte therapy (TILT), engineered T-cell receptor therapy (ETCR), and chimeric antigen receptor T-cell therapy (CARTCT). Below is a comprehensive compilation of the various categories of immunotherapies that are either in the developmental stage or already accessible. There is not enough information provided to rewrite the text in a straightforward and precise manner[33].

Hyperthermia

In addition to other cancer treatments such as surgery, radiation, chemotherapy, gene therapy, and immunotherapy, hyperthermia (HT) is also a method of treatment.1 Hyperthermia (HT) is a procedure used in oncology to raise the temperature of tissue using an external heat source. This can either eliminate cancer cells or limit their future growth[34]. Two Hyperthermia encompasses several techniques for administering heat, which are used in combination with other cancer therapies, particularly chemotherapy and radiotherapy. Based on the results of most studies, elevated temperatures cause direct harm to cancerous cells, hence increasing their susceptibility to other forms of treatment. Moreover, elevated temperatures amplify the efficacy of radiation and chemotherapy treatments while inflicting minimum or negligible harm to healthy tissues[35]. Therefore, HT is commonly used as a further therapeutic approach for cancer. The temperatures for the HT treatment range from 40 to 48 degrees Celsius, and the temperature is maintained at the treated site for a minimum of one hour[36]. Temperatures over fifty degrees Celsius can be referred to as coagulation, temperatures ranging from sixty to ninety degrees Celsius can be referred to as thermal ablation, and temperatures surpassing two hundred degrees Celsius can be referred to as charring. Ablation, specifically high temperatures, referred to as number five HT, involves the direct administration of chemical or thermal treatment to a cancer with the goal of completely eliminating or causing substantial damage to the tumour.8. The curative capacities, treatment expenditure, technological difficulties, and evidence of success can vary greatly depending on the HT approach used.9) Despite the historical usage of hyperthermia (HT) for tumor treatment dating back to ancient Greece, the application of this

ISSN: 2583-4053

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https://doi.org/10.55544/jrasb.3.2.41

technology has faced criticism due to its limitations. Some examples of these challenges include the incapability to heat the target without harming neighboring cells, the difficulty of achieving consistent heat distribution throughout the tumor, and the inherent complexities of targeting undetectable micro metastases[37].

Recently, there have been significant breakthroughs in the field of nanoparticle-assisted thermal therapy, which hold promise for addressing most of these concerns. However, there are still lingering concerns over the use of nanoparticles. Although it has been previously proven that normal tissues exhibit greater thermotolerance towards cancer cells, the underlying mechanisms for this phenomenon remain mostly unknown[38]. Various therapy procedures can be utilized based on the tumor's location, such as whether it is superficial or deep-seated.

Hydrogel materials have multiple sizes and multiple delivery routes

Hydrogels, characterized by their unique three-dimensional networks of hydrophilic polymers, have become a fundamental aspect of biomaterial research, and have greatly impacted various biomedical sectors [38]. These networks have the ability to absorb and retain large amounts of water. They are distinguished by their impressive ability to expand without breaking, therefore maintaining their structural integrity through the employment of cross-linking mechanisms that can be either chemical or physical [39]. Due to this inherent property, hydrogels can replicate the physicochemical traits of the natural extracellular matrix. Consequently, they are very suitable for use in drug delivery systems [40], tissue engineering [41], wound healing [42], and various other fields, as depicted in Figure 1. The field of hydrogel research has a rich history of innovation, seen in its successful integration into the realm of biological sciences. This evolution demonstrates the versatility of these materials in terms of problem-solving.

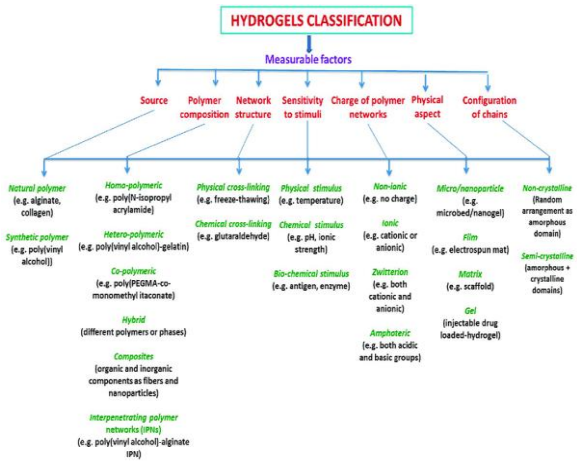

Fig. 3: Illustration of hydrogel classification based on cross-linking methods and their biomedical applications.

In the 1960s, Wicht Erle and Lim developed poly(hydroxyethyl methacrylate) (pHEMA) hydrogel, which initiated the use of hydrogels as biomaterials. This work laid the foundation for the advancement of hydrogel technology and was a pioneering endeavor. The exponential growth of the field of polymer research can be attributed to significant discoveries and a better understanding of biological interactions [43]. The structural dynamics of hydrogels, especially in drug administration for biomedical purposes, have been extensively studied through experimental research. Additionally, theoretical frameworks and computer modelling have played a vital role in providing further insights into this area [44]. The list of attributes they provide includes insights such as elasticity, porosity, and mesh size. These prediction models, based on thermodynamic principles, have enabled the production of hydrogels with customized properties for specific biomedical uses. Hydrogels can be classified into three primary categories: natural, synthetic, and semisynthetic. The categories are determined by the hydrogels' source and the specific cross-linking mechanisms involved [45]. This classification highlights the importance of achieving a balance between the rates of biodegradation and mechanical strength. It is essential to attain optimal biocompatibility and utility. In order for hydrogels to be considered biocompatible, it is imperative that they are non-toxic and do not elicit any undesirable immunological responses. Modifying the inherent characteristics of a material, like its permeability, expansion, and durability, is essential to render it suitable for a certain application, such as delivering medication or constructing biological tissues[46]. This further exemplifies the adaptability of polymeric materials, allowing for the tailoring of hydrogel characteristics to fulfil the demands of certain biological applications. The adaptability of hydrogel polymerization techniques is enhanced by the evolution of various methods, such as the formation of homopolymers, copolymers, and interpenetrating networks.

The power of hydrogels to respond to external stimuli, such as chemical, physical, or biological factors, has created new opportunities for the advancement of intelligent materials [47]. This characteristic is crucial for the development of dynamic hydrogel systems that can adapt to various physiological conditions. These technologies will facilitate the development of enhanced applications in fields such as flexible tissue scaffolds, reactive biomedical devices, and intelligent drug delivery systems. This represents a significant advancement in the progress of less intrusive therapy approaches [48]. Injectable hydrogels, known for their ability to undergo shear thinning and self-healing, have been utilized. These hydrogels have the potential to be a valuable alternative to traditional surgical methods since they can deliver medication and heal tissue directly at the site of action. However, the journey towards the clinical application of

ISSN: 2583-4053

Volume-3 Issue-2 || April 2024 || PP. 242-251

https://doi.org/10.55544/jrasb.3.2.41

these materials is filled with challenges, the most important of which is the need to prevent unfavorable immune responses and ensure the removal of harmful by-products generated during the cross-linking process [49]. Recent advancements in nanotechnology have led to the development of a new category of hydrogel-based nanomaterials. These materials show great promise in the fields of drug delivery and tissue engineering [50]. Nanogels are an innovative category of nanomaterials. With the progress in three-dimensional bioprinting [51], hydrogels have become the leading method for producing tissue structures with exceptional precision and intricacy. This marks the commencement of a novel era in the domains of regenerative medicine and tissue engineering.

III. ROLE OF MRI MONITORING IN THERAPEUTIC HYDROGEL SYSTEMS

One approach to achieving long-lasting therapeutic medication levels in the brain is by using implanted biomaterials that have controlled polymer degradation and enable the drug to spread evenly. The difference between 12 and 14 is -2. Hydrogels, currently under investigation for their possible use in various biomedical domains such as regenerative medicine and controlled drug delivery, have the potential to be used as the basis for orthopedic implants. The difference between 15 and 17. These hydrophilic polymer networks, which have a three-dimensional structure, have the ability to absorb and retain large quantities of water. This characteristic creates possibilities for use in neural tissue engineering. The reason for this is that they offer a method for replicating the extracellular matrix (ECM).The coordinates represent a point in a two-dimensional space. Hydrogels are highly adaptable, allowing for the loading and controlled release of medicines or proteins based on the diffusivity of the loaded protein inside the hydrogel matrix. Consequently, the protein's dependence is contingent upon both its size and the mesh size of the hydrogel network, as evidenced by the cross-link density of the hydrogel.[51]. Conversely, the latter can experience gradual development due to swelling and degradation of the matrix. Injecting a hydrogel containing medication or protein directly into the brain can bypass the blood-brain barrier and create a localized reservoir for controlled release.

Stimuli-sensitive hydrogels, which may react to many environmental factors such as chemical compounds, temperature, pH, pressure, electric field, etc., have gained increasing attention in recent decades. The time period is 2021-22. In situ gel-forming hydrogels are a promising drug delivery method for addressing injuries and illnesses of the central nervous system (CNS). These hydrogels belong to the category of stimuli-sensitive hydrogels. Prior to administration, these gels exist in a liquid state; but, upon injection into a particular organ, such as the brain, they undergo a transformation into a three-dimensional structure. The given input is a list containing the elements [52]. At low temperatures, these substances can dissolve in water, whereas at high temperatures, they can come together on their own to form structures. This property makes them highly suitable for creating hydrogels that are sensitive to temperature changes. Polymers that exhibit lower critical solution temperature (LCST) behavior, with their cloud point ideally situated between room temperature and body temperature, are very suitable for the development of thermosensitive hydrogels [55]. Due to the need for long-term protection against ongoing damage or support for recovery processes in brain-related pathological conditions, hydrogel-based drug delivery systems are an attractive method for controlled release of therapeutic doses of protective and growth-promoting substances." Several research have investigated the effectiveness of the three-dimensional porous structure of thermosensitive hydrogels in loading and releasing medications and growth factors in the central nervous system (CNS) to promote tissue regeneration. The effectiveness of a drug delivery system depends on the careful customization of its design and release qualities to ensure both biocompatibility and the presence of the therapeutic component at the intended site of administration. Therefore, accurate measurement and comprehension of the kinetics of release are crucial in the process of therapeutic translation. Conventional in vitro investigations of drug release, especially those involving hydrogels loaded with proteins, usually require placing material samples in near sink conditions[56] These settings consist of phosphate-buffered saline (PBS) placed on top of the gel. The samples are subsequently extracted from the release medium at different time intervals, and subsequently substituted with fresh PBS conditions.30 percent Subsequently, the medication's concentration in the collected release samples is determined using either Ultra Performance Liquid Chromatography (UPLC) or UV-visible spectrophotometry. Furthermore, advanced techniques including fluorescence recovery following photobleaching have been employed to study the movement of proteins inside a hydrogel matrix. [57]. Hence, it is imperative to devise approaches that facilitate the assessment of protein drug delivery from locally administered depots without involving any invasive procedures. Magnetic resonance imaging (MRI) is a highly adaptable imaging technique that is distinguished by its exceptional ability to differentiate between soft tissues and its lack of restrictions on imaging depth. This imaging technique has the capacity to provide in vivo assessment of the distribution or release of locally administered medications, as well as the impact of these medications on the structure and function of tissues.[58][59][60]. An example of this is the successful

ISSN: 2583-4053

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https://doi.org/10.55544/jrasb.3.2.41

evaluation of local drug release in tumor-bearing animals after the systemic delivery of thermosensitive liposomes filled with a drug-MRI contrast agent complex. This study utilized transient MRI contrast enhancement after targeted heat to collect precise information about the site and timing of triggered content release. The number is subtracted from. Magnetic resonance imaging (MRI) can be employed not only to monitor medication release but also to identify alterations in the volume of hydrogel. These changes can arise due to several variables, such as fluctuations in external conditions including temperature, pH, light, electric field, and pressure, as well as the deterioration and subsequent expansion of the hydrogel substance.

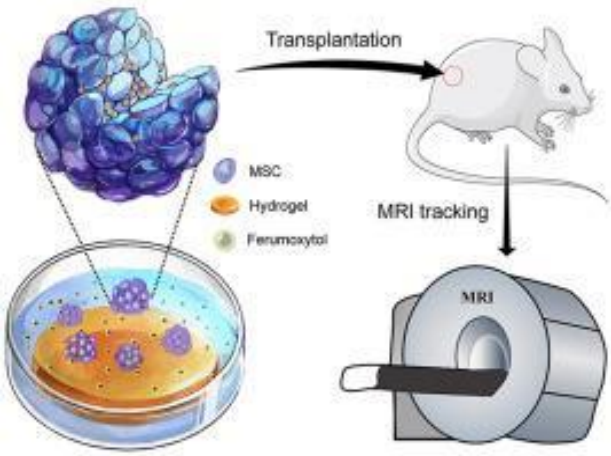

Fig: 4 Extracellular magnetic labeling of biomimetic hydrogel-induced human mesenchymal stem cell spheroids with ferumoxytol for MRI tracking

IV. CONCLUSION

Brain tumors have limited therapeutic choices, with chemotherapy being one of them. The key drawbacks of chemotherapy are its lack of efficacy and the presence of systemic toxicity. Given the elevated rates of recurrence, tumor excision alone becomes inadequate. There is a demand for novel therapeutic strategies, and hydrogels have shown promise as a potent tool against brain tumors. Due to their unique characteristics, such as excellent biocompatibility, biodegradability, and responsiveness to stimuli, these materials are highly suitable for use in both localized and systemic drug delivery. Injectable hydrogels with nanostructured drug delivery systems (DDS) exhibit targeted and controlled drug release to the tumor, decreased toxicity in healthy tissues, and efficient inhibition of cancer development and recurrence. Customized nanogels have recently become an appealing method for effectively transporting chemotherapy medicines to cancerous brain cells. This technique has arisen as a resolution to the issue of employing highly intrusive interventions. By effectively breaching the blood-brain barrier (BBB) and undergoing selective absorption, they managed to precisely find and eliminate cancer cells without causing harm to healthy organs. This was achieved by integrating the characteristics of hydrogel with nanoparticles. It is encouraging to witness demonstrations of proof-of-concept utilizing live models; nonetheless, further study is required to facilitate a smooth transition to clinical use.

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