

Preliminary Study: Silicone Oil Based Magnetic Fluid as A Vitreous Cavity Tamponade

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Abstract: The paper aims at investigating the potential application of silicone oil based Fe_3O_4 magnetic fluid as a vitreous tamponade agent. The silicone oil based Fe_3O_4 magnetic fluid is prepared and deposited in a pig eye. An external magnetic field is applied to the eye to test the behavior of the fluid in vitro as well as the tamponade effect of the magnetic fluid. In the vitro study, it shows that under the influence of an external magnet, the magnetic Fe_3O_4 micelles are separated from silicone oil toward the maximum magnetic field strength (toward the magnet) and coated on the inner scleral wall evenly in that area. The experiment result provides the preliminary data supporting silicone oil based Fe_3O_4 magnetic nanoparticles as a novel vitreous tamponade agent, especially in the case of inferior retinal detachments.

Key words: vitreous cavity; silicone oil; magnetic fluids

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Vitrectomy followed by vitreous cavity tamponade is a well accepted treatment for retinal detachment. In addition to good biocompatibility and stability, an ideal tamponade agent would be capable of maintaining pressure in all directions in the vitreous cavity^[1-2]. However, a major limitation of currently available agents, such as SF₆, C₃F₈ and silicone oil, is that they are less dense and hence more buoyant than intraocular fluid. Thus patients with inferior retinal detachment must keep the prone position post-operatively to maintain adequate tamponade pressure inferiorly when gas is used. When using silicone oil, the oil must fill the eye significantly interfering with postoperative vision.

In recent years there has been a surge of interest in nanotechnology based magnetic fluids^[3] and their potential biological applications^[4]. Such application include, but are not limited to, immunoassays, micro-vascular surgery and anti-neoplastic medications^[5-9]. Herein we investigate the potential application of magnetic fluid as a vitreous tamponade agent. If its magnetic properties can be utilized to control the vector of tamponade, magnetized fluid can obviate the burden of post operative patient positioning as when injecting gas, or the need to completely fill the eye when using Silicone oil. In the current study, we described the preparation of silicone oil based Fe_3O_4 magnetic fluid

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and tested its magnetic properties in the vitreous cavity in vitro.

1 Methods

1.1 Preparation of magnetic Fe_3O_4 powder

Fe_3O_4 powder was prepared as previously described in detail by Zhang et al^[9]. Materials: Analytically pure $\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$, $\text{Fe}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$, $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$, FeCl_3 , NaOH , citric acid, sodium laurate, ethanol, H_2SO_4 98%, dimethyl silicone polymer (Acri.Sil.ol 5000). with viscosity of 5 000 cP. Instruments: 85-2 magnetic stirring apparatus; water bath (temperature control accuracy at 1 °C), FSH-2 high-speed refiner, PHS-25A acidometer, vibrating magnetometer VSM (0~1 T continuous adjustment is allowed). In brief, $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$, FeCl_3 and citric acid were mixed according to the molar ratio of 1:2:3 using the magnetic stirring apparatus. The mixture was then precipitated by adding 2 mol·L⁻¹ of NaOH solution. The precipitated magnetic Fe_3O_4 powder was incubated at the temperature of 65 °C for 1 h before it was brought to room temperature. It was then neutralized by a deionized water wash, dried and frozen.

1.2 Preparation of silicone oil based magnetic liquid

To prepare the liquid, 0.18 g of Fe_3O_4 particles and 0.05 g of sodium laurate were mixed in a beaker, followed by 3.35 g dimethyl silicone polymer which was added into the mixture. The mixture was stirred in the beaker using the ultrasonic stirrer for 40 min at the temperature of 37 °C. After the magnetic micelles were evenly distributed in the silicone oil, the fluid was centrifuged, and the lower layer containing the larger sized Fe_3O_4 micelles was discarded. The Fe_3O_4 magnetic fluid was obtained from the upper layer of the fluid.

Magnetic micelles in the silicone oil were photographed using transmission electron microscopy JEM-100CX (Ningbo Institute of Materials Technology & Engineering, Chinese Academy of Sciences). The average micelle size was calculated by statistical

average. The magnetization curve of the magnetic fluid was tested under the temperature of 25 °C.

1.3 Behavior of the magnetic Fe_3O_4 micelles in silicone oil under the influence of an external magnetic field

In order to test the behavior of magnetic Fe_3O_4 micelles in silicone oil, 0.2 mL of the magnetic fluid was placed onto a plastic membrane. A magnet with a surface magnetic field strength of 350 mT was placed under the membrane. Photos were taken to document the movement of the magnetic Fe_3O_4 micelles on the membrane.

1.4 In vitro study of the tamponade effect of the silicone oil based magnetic fluid

The properties of the magnetic fluid were tested in the vitreous cavity of a pig eye. To best observe the movement of the magnetic fluid in the vitreous cavity the pig eye was dissected and the cornea, lens, vitreous cavity, retina and choroid were all completely removed. Prior to injection, the prepared silicone oil based Fe_3O_4 magnetic fluid was first stirred using the vibrating platform for 10 s, followed by sterilization. After sterilization, 0.2 mL of the silicone oil based magnetic fluid (containing 1% nanometer Fe_3O_4 micelles) was injected directly into the vitreous cavity. A magnet with surface magnetic field strength of 350 mT was placed outside the scleral wall to generate the external magnetic field. Photos were taken to document the movement of the magnetic fluid in the vitreous cavity under the influence of the external magnetic field.

2 Results

2.1 Movement of the magnetic Fe_3O_4 micelles in the silicone oil under the influence of external magnetic field

2 min after the external magnetic field was generated, the magnetic Fe_3O_4 micelles aggregated in a donut shape along the external magnetic field and the silicone oil turned transparent (Figure 1). When the membrane was pulled up, the magnet remained attached

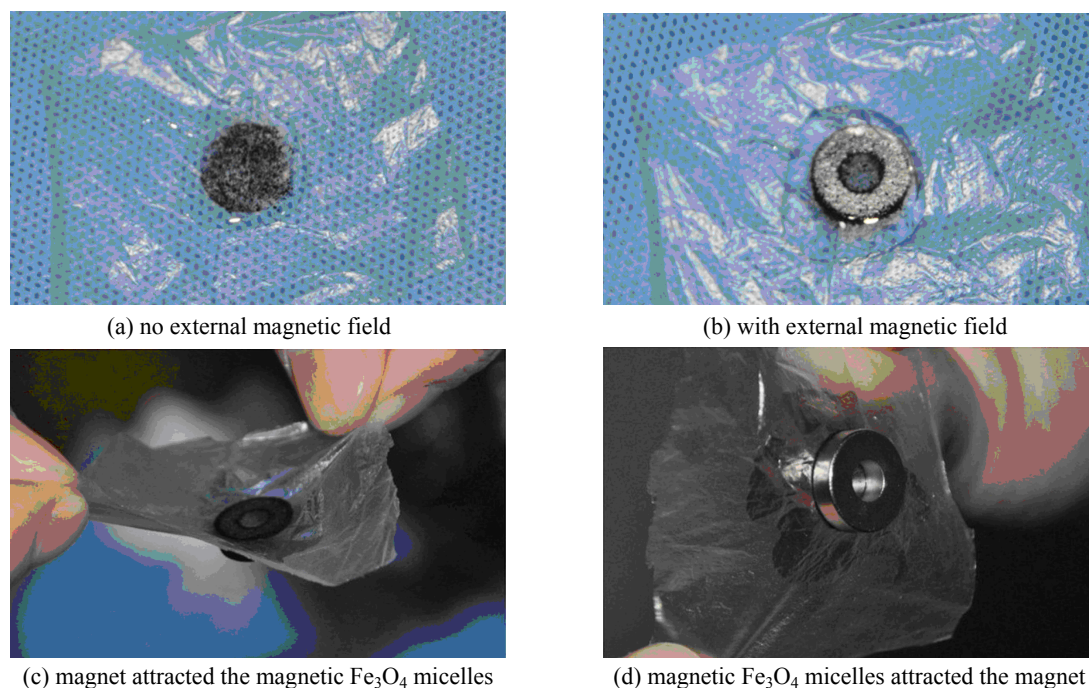


Figure 1 Motion of the magnetic Fe_3O_4 micelles in the silicone oil base in magnetic field

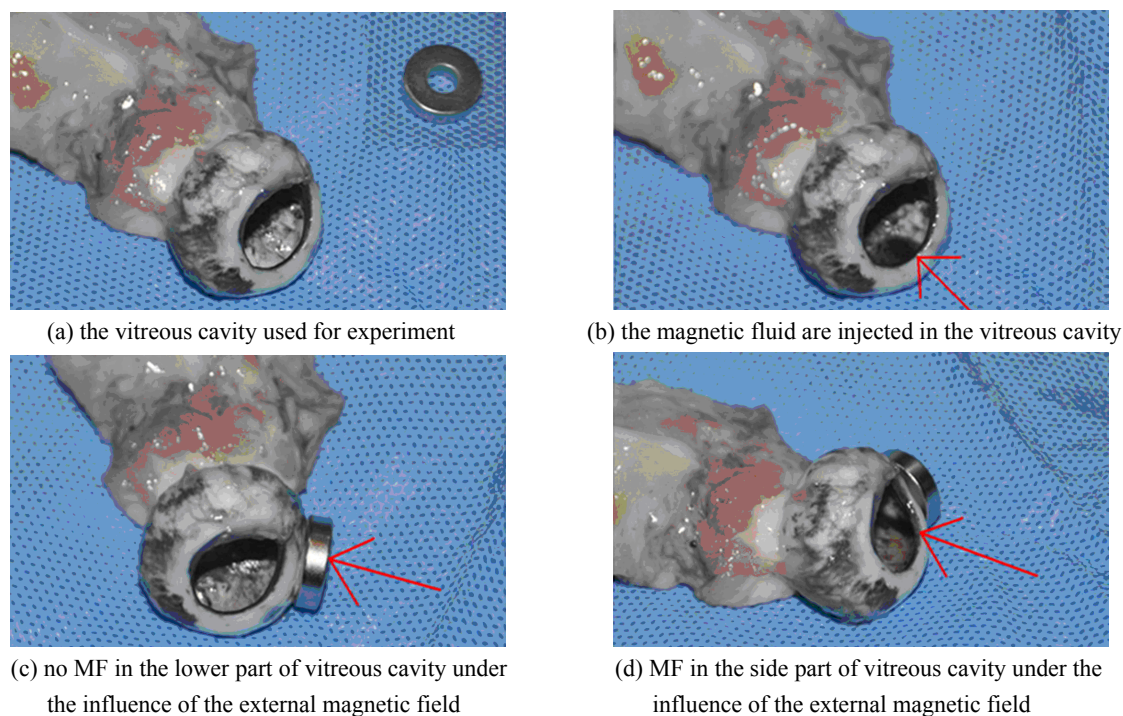


Figure 2 Vitreous cavity before and after injecting magnetic fluid

to the membrane, indicating that the magnetic Fe_3O_4 micelles generated a magnetic force to attract about 30 g magnetic blocks.

2.2 In vitro study of the tamponade effect of the silicone oil based magnetic fluid

The external magnet was then placed alongside the

eyeball to generate the external magnetic field. After 2 min, it was observed that most of the magnetic Fe_3O_4 micelles separate from silicone oil toward the maximum magnetic field strength (toward the magnet) and coated the inner scleral wall evenly in that area, as shown in figure 2. The silicone oil base became transparent. We

also observed that when the magnet moved along the eye ball wall, the magnetic micelles followed the magnetic field and moved accordingly inside the vitreous cavity (pictures not shown).

3 Discussion

Researchers and clinicians have long sought to develop versatile vitreous tamponade agents that are effective regardless of the retinal detachment location. However, none of the commonly used tamponade agents, including SF₆, C₃F₈, and silicone oil, is ideal in cases of inferior retinal lesions because they are less dense than intraocular fluid and do not provide good support to the inferior portion of the retina [10-11]. It has been reported that the postoperative recurrence rate for complex retinal detachment repair using traditional tamponade agents could be as high as 10% to 20%^[12] and even higher in the presence of proliferative vitreoretinopathy (PVR), as PVR has a propensity to occur in the inferior retina^[13].

In recent years, heavy silicone oil (Densiron) was introduced as a tamponade agent that “sinks”. Lim et al^[14] reported a case series of 10 cases in which Densiron was used in eyes which had failed initial inferior retinal detachment surgery. They reported an overall success rate of 70% for long-term total reattachment, with significantly improved postoperative visual acuity. In contrast, Sandner et al^[15] reported a primary anatomical success rate of 33.3% in their case series of a total of 12 patients. In addition, they documented a spectrum of Densiron related side effects, including temporary inflammatory reaction/fibrin accumulation, moderate-to-severe intraretinal fibrosis, elevated intraocular pressure, emulsification, sterile hypopyon, vitreous hemorrhage and chronic hypotony. Up till now, evidence has supported Densiron as a promising tamponade agent for inferior retinal lesions. Yet for superior retinal lesions, it is far from ideal because it does not support the superior portion effectively and it may even induce PVR superiorly due to the traction at upright position.

In the current study, the silicone oil based Fe₃O₄ magnetic fluid demonstrated several unique properties which might make it useful in many retinal detachment cases. We observed that the external magnet was able to control the vector of the micelles which then smoothly coated the inner surface of the sclera. Moreover, the micelles generated localized pressure on the wall determined by the direction of the external magnetic field.

These properties highlight the potential advantages of using silicone oil based Fe₃O₄ magnetic fluid over current tamponade agents in the clinical setting. Magnet localization would supplant head positioning, obviating concerns of patient compliance with post-operative head positioning. Rather than having to maintain the prone position, a patient with an inferior retinal detachment may sooner go about their normal daily activities.

Moreover, it was also observed that the silicone-oil vehicle turned clear when the fluid was magnetized to allow for good post-operative vision.

Our findings, while promising, are very preliminary in nature. Further investigations are required to elucidate the biocompatibility, dosage and in vivo effectiveness of this new material. Studies must also examine the effect of nanoparticles on the surface tension of the fluid. In addition to buoyancy, the surface tension of oil or gas normally acts to tamponade the break itself and prevent fluid from entering the subretinal space. A significant breakdown in surface tension of the silicone oil could allow fluid, oil or even the nanoparticles themselves to enter the subretinal space.

Although this field is in the very early stages of development, we are nevertheless optimistic about this potentially novel application of nanoparticle technology in the field of ocular therapeutics.

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硅油基磁性流体作为玻璃体腔填充剂的初步研究

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摘要: 通过制备的硅油基磁性流体, 将其注入猪的眼球内, 在外磁场下观察流体在眼球内壁的运动行为, 探究其作为填充剂的效果。研究结果表明: 从磁性流体的实时运动行为中可以看出, 在外磁场作用下磁性颗粒从硅油基磁性流体中分离出来, 携带部分硅油移到磁场强度高的地方并覆盖其局部位置。实验结果为磁性液体作为新型玻璃体填充剂提供了一定的数据支持, 在视网膜脱离修复中将有很好的应用前景。

关键词: 玻璃体腔; 硅油; 磁流体

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