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# Design and Development of a Magnetostatic Pump for Blood Pumping

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***Abstract***
Nowadays numerous patients suffer from blood damage. Specifically, hemolysis is damage to the blood cells that trigger the release of hemoglobin into the blood plasma that can cause morphological changes and biomedical alterations Mechanical shear stress plays an important role that drives the rupture of red blood cells. In this work, a novel magnetic pump is designed and built with the aim to use it in extracorporeal membrane oxygenation (ECMO). The operation of this pump is based on the controlled movement of magnetic particles (ferrofluid) that have been added to the blood stabilized by a quadrupolar magnetic field. A special chamber is designed and built to enter and exit the blood as well as to keep the ferrofluid in the cycle within the blood. In this study, the effect of flow rate (maximum 150 mL/min) on plasma-free hemoglobin (PFH) is investigated.

***Keywords*:** magnetic pump, hemolysis, blood pumping, ECMO system, optimization, design

## 1. Introduction

Nowadays, numerous patients suffer from blood damage. This disease can be caused due to various factors such as mechanical, chemical, and osmotic forces, as well as heat. In some cases, in addition to blood cells, plasma proteins are also damaged and their function is altered[1]. Hemolysis is a well-known blood disease that consists on the rupture of the red blood cells.

Extracorporeal membrane oxygenation (ECMO) has become an essential tool for the treatment of patients with severe heart and lung failure. Numerous researchers have developed conventional treatments that have not been effective. ECMO is a device that circulates blood outside the body using a pump. Outside the body, blood is saturated with oxygen, and carbon dioxide is excreted[2]. A comprehensive census found that of the 78,397 patients who used ECMO due to respiratory and cardiac failure, 58% were generally rescued by discharge[3].

In ECMO devices and blood pumping, two factors play a key role in the formation of hemolysis. The first factor is thrombosis, which is the result of the pump and oxygenator function. The second factor is the excessive mechanical stress as a result of pump operation[4].

Different types of centrifugal and roller pumps are widely used in ECMO devices[5]. Laboratory data from clinical experience have shown that centrifugal pumps increase hemolysis. During the process of this type of pump, hydrodynamic cavitation is an inevitable phenomenon which leads to evaporation and bubble production. Bursting of bubbles leads to temporary high shear in the blood cells, which would ultimately damage them[6]. As an alternative, previously in our group, they introduced the concept of magnetic pumps. The results of the analysis of circulating blood cells in a magnetic pump have shown that this type of pump is a suitable option for the gentle transportation of blood. The results of plasma-free hemoglobin (PFH) show a low rate of hemolysis in this type of pump. As a result, these pumps cause less damage to blood cells compared to peristaltic pumps[7]. The magnetic pump presents a range of advantages such as the lack of moving of an internal part, no blood contact with the pump, low power operation, and constant temperature. The magnetic pump relies on the transfer of fluid within a ferrofluid in a magnetic field[7]. Ferrofluids are colloidal liquids of magnetite ($Fe_3O_4$) nanoparticles suspended in a carrier fluid[8]. The applied magnetic field causes the magnetic particles to move inside the tube or control the flow[9]. Here, in this paper, we introduce a novel magnetic pump design that lowers considerably the effect of hemolysis and platelet aggregation.

## 2. Design and methods

### 2.1. Blood collection and analysis

Human blood was acquired from regular, medication-free and non-smoking donors provided from l'Établissement français du sang (EFS) in Strasbourg France. To obtain PRP, each sample was centrifuged in a SORVALL RC3BP centrifuge. The light transmission aggregometry (LTA) method is used to analyze platelet aggregation[10]. Aggregation was expressed as the maximum percentage change in light transmittance from the baseline

### 2.2. Construction of magnetic pump

The magnetic pump parts were 3D-printed using F170 (Stratasys) with ABS (acrylonitrile butadiene styrene)-M30. Figure (1-a) shows of blood centrifugal pumps and Figure (1-b) shows a roller pump used in the blood circulation. The designed and home-built magnetic pump in this study is shown in Figure (1-c-d). The operation of a magnetic pump is based on the force exerted by the magnetic field generated by the magnet on the ferrofluid. The movement of magnets and the presence of ferrofluid particles, in a circular motion, cause the liquid to move in the tube. Magnetic field during the chamber cycle has a great effect on the movement of ferrofluid in the tube. To create the magnetic force, a quadrupole consisting of four magnets with a channel in its center was considered. In this model, the magnets were arranged in the form of a plus sign (see the design in Figure (1-e)). The tube was introduced in the hollow, in the center of the magnets.

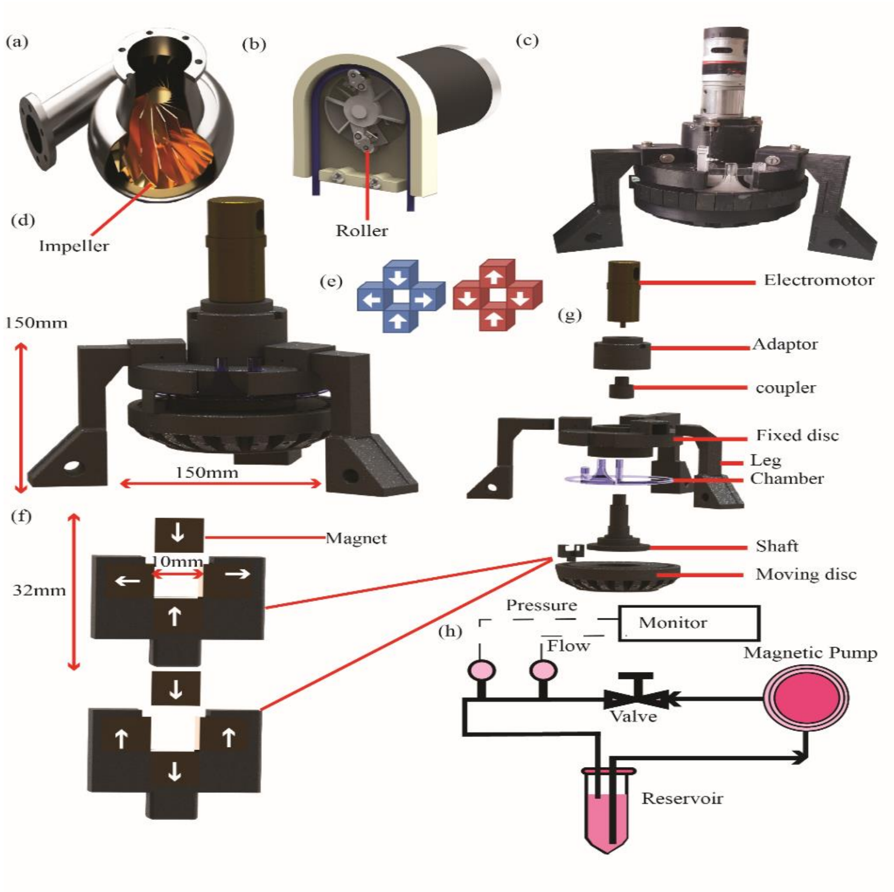


**Figure 1.** a) type of centrifugal pump used in the circulation. b) A kind of roller pump. c) Assembled magnetic pump after printing. d) Prototype of the designed pump. e) Two arrangements of magnets designed to create a pinching point as well as the space between them to pass the channel. f) Design of a magnet holder that shows how to place the three magnets g) a collapse view of the pump showing the main internal components. h) Experimental setup

## 3. Results

For blood tests, the set-up was used as in Figure (1-h). The experiments were performed in a closed cycle with flow rate control. Calculation of plasma-free hemoglobin (PFH), which results from hemolysis, can show the extent of destruction of red blood cells by mechanical stress. In this study, we monitored PFH at three flow rates of 50, 110, and 150 mL.min-1 in the magnetic pump. Figure (2-a) shows platelet aggregation changes with three types of agonists in the flow rate of 110 ml.min-1. Individual platelet aggregation results were obtained before and after pumping. After 8 minutes of platelet aggregation monitoring, the amount of change compared to the control sample for Adenosine diphosphate (ADP), collagen (2.5 µg.ml-1), Colgan (1.25 µg.ml-1) and Arachidonic acid (AA) enzymes were 8%, 2.1%, 3.3%, and 3% respectively. Platelet-rich plasma was obtained from whole blood centrifugation after pumping. The concentration of plasma-free hemoglobin for 50, 110, and 150 mL.min-1 flow rates were 32, 35, and 36 mg.dL-1 respectively (2-b). With increasing the flow from 50 mL.min-1 to 110 mL.min-1, about an increase of 8% in PFH was observed. While increasing the flow from 110 mL.min-1 to 150 mL.min-1 resulted in a rise in the PFH of about 2.5%.

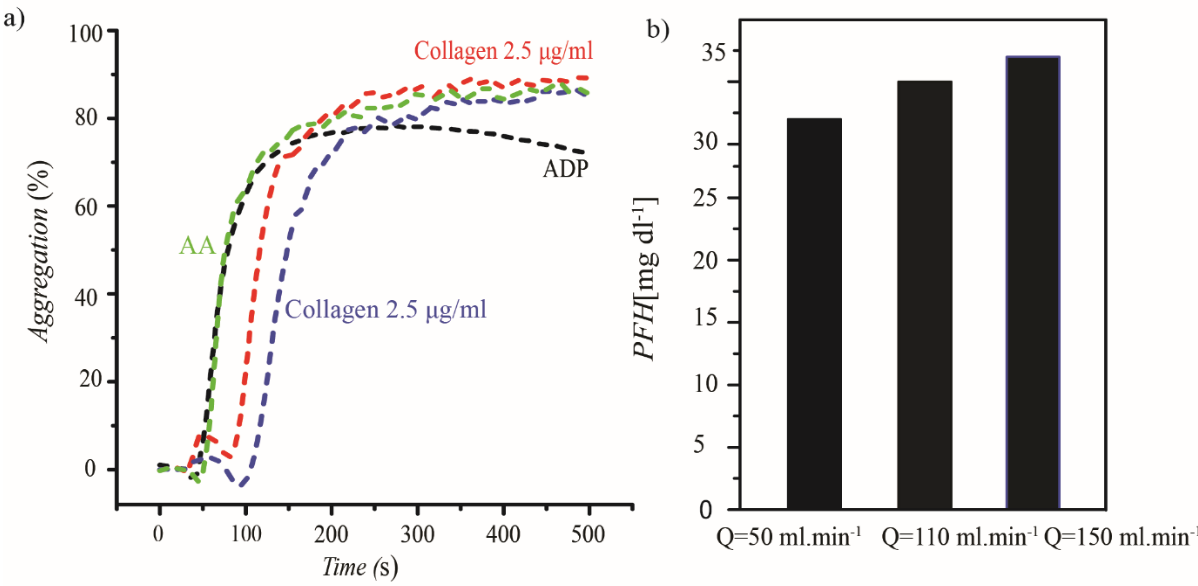


**Figure 2.** a) The degree of platelet aggregation activated by three agonists tested for PRP from blood after pumping. b) The rate of hemolysis in different flow rates

## 4. Conclusion

In this study, a new pump for blood transfusion was designed and built. Its function was also tested for hemolysis in different blood flow rates. This pump has a very good function for blood transfusion in terms of hemolysis. This pump can also be used for gentle blood transfusion. Our goal in the future is to design the same type of pump with the ability to pump blood at higher flow rates and compare this pump with the pumps available in ECMO devices in higher flow rate.

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