<u>Description of the PhD Research Proposal -</u>

1) **Title of the PhD thesis**:

Design, modeling and control of magnetic microrobots for minimally invasive brain surgery

2) **Name of the Principal Investigator**:

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3) **Brief description of the key objectives :**

The aim of this PhD thesis is to design and develop a new microrobotic platform, namely Brain-MagBot (BMB), which provides a minimally invasive means for targeted therapeutic interventions in specific brain areas *in vivo*. The BMB is capable of performing navigation of magnetic microrobotic swarms (artificial helicoidal microrobots) to swim from the spinal cord into the brain via the cerebrospinal fluid (CSF). The main goal of this project is to realize microrobotic stem-cell-delivery to specific brain areas using a swarm of magnetic microrobots for therapeutic intervention of traumatic brain injury (TBI).

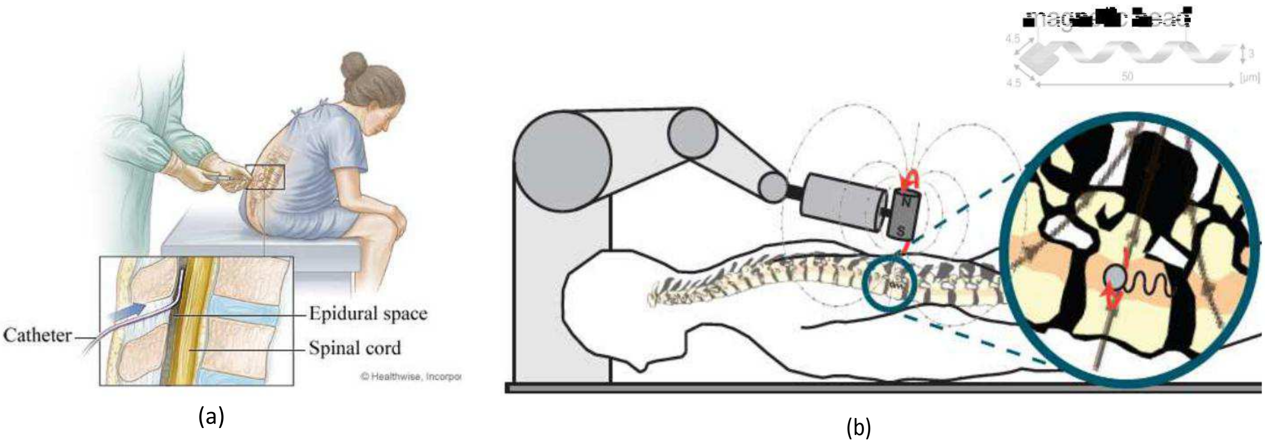


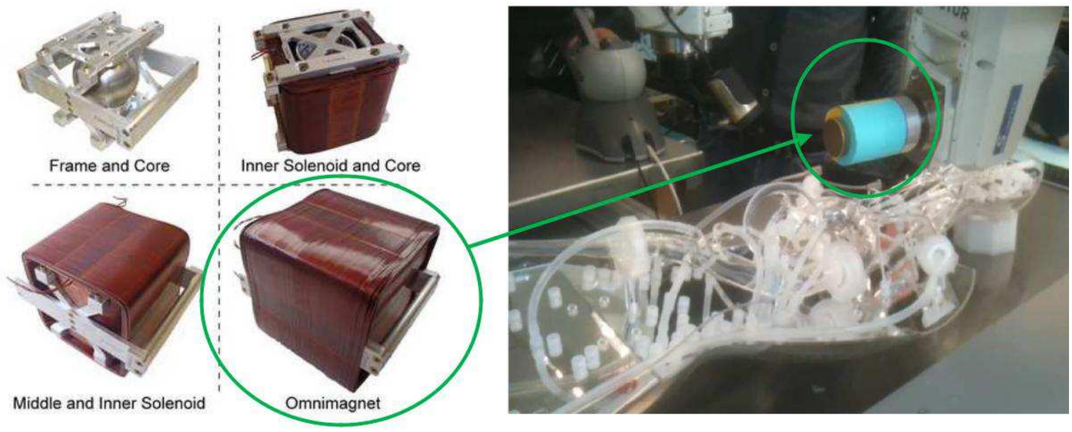
Figure 1: Conceptual images of BMB platform: (a) Injection through a catheter swarms of artificial magnetic microrobots in the epidural space of the spinal canal, and (b) propulsion of the microrobots (inset) through the spinal canal using a multidegree of freedom-magnetic manipulator.

The medical procedure is described as follows. First (Fig.1a), a sterile guide needle and a small tube (epidural catheter) is inserted into the space between the spinal cord and outer membrane of the spinal cord (epidural space in L2-L3 lumbar). The epidural catheter is placed at or below the waist. The doctor first uses a local anesthetic to numb the area where the needle will be inserted. Then the guide needle is inserted and removed, while the catheter remains in place and injection of the microrobots are performed. Then (Fig.1b), the propulsion and steering of the magnetic helicoïdal microrobots evolving in the cerebral spinal fluid (CSF) is controlled through real-time imager (2D ultrasound or CT scans) along the spinal canal using a rotating-magnetic manipulator. Finally, the stem-cell delivery is performed in the brain.

4) **Research Work Plan :**

The essential technical objectives of this proposed PhD work are essentially focused on the design, modeling and control of the multidegree of freedom (dof) magnetic manipulator for the propulsion and steering of the swam magnetic microrobots. The key points are listed as follows.

i) Literature review on magnetic-field-generation systems using electromagnetic coils.
ii) Design and modeling of novel multi-dof magnetic-field-generation systems based on orthogonal arrangement of electromagnetic coils for helical magnetic microrobot propulsion (See Fig.2a) [1].
iii) Five-degree-of-freedom manipulation of an untethered magnetic microrobots in fluid with motion and force control [2].



(a) (b)

Figure 2. (a) Prototype of 5dof magnetic actuator (Omnimagnet) to be implemented as a robotic end-effector for untethered control of helical magnetic microrobotots and (b) trajectory control along the spinal cord of a human-like phantom model.

iv) A multi-degree-of-freedom robotic arm connected with a 5-dof magnetic actuator (Omnimagnet) will be designed and prepared which is capable of propelling/steering the microrobots to swim inside human spinal cord model (see Fig.2b) with a body-scale travelling distance.
v) Then, experimentation and validation of prototype for safe, controlled and robust propulsion of magnetic microrobots will be carried out.
vi) Finally, electromagnetic coils with a specific design for remote control of the microrobots in the brain will also be designed and prepared for targeted cell delivery experiments [3].

5) **Brief collaboration plan, including also information on the following:**

The collaboration will focus on the development of microrobotic platform (BMB) as well as the microrobotic swarms which is capable of performing stem cell delivery in specific brain areas. The French supervisor is working in collaboration with the Chinese University of Hong Kong (CUHK) that are responsible for the design and mass production of the artificial magnetic microrobots. Meanwhile, the supervisor from France will be in charge of the design and the development of a human-scale phantom for the investigation on microrobotic delivery of the robots with payload, i.e. stem-cells, from the spinal cord area to a specific brain region. Afterwards, a collaboration with the medical school at CUHK and the Prince of Wales of Wales Hospital, will be in charge of the animal tests of using the magnetic microrobotic swarm and the platform, and investigate the efficiency of the stem-cell therapy using BMB. The hospital will also assist the research teams to get access and advice on the *in vivo* imaging system, such as IVIS and MRI. In the HK team, from the faculty of engineering and the faculty of medicine, have complementary research background and expertise on magnetic microrobots and brain/neurosurgery, respectively. Furthermore, the French supervisor has long term experience in the development of micro/nanorobotic platform for cancer treatment. Prof. Ferreira was the project coordinator of a European project NANOMA - Nano-Actuators and Nano-Sensors for Medical Applications, at FP-7, in which novel controlled nano-robotic delivery systems was proposed and developed to improve the administration of drugs in the treatment and diagnosis of breast cancer. The total budget of that EU project was over 3.3 million EURO with eight partners from Europe.

6) **Bibliography:**

[1] J. Petruska and J. J. Abbott, "Omnimagnet: An Omnidirectional Electromagnet for Controlled Dipole-Field Generation," IEEE Trans. Magnetics, 50(7):8400810(1-10), 2014.

[2] A. J. Petruska and J. J. Abbott, "Five-degree-of-freedom Manipulation of an Untethered Magnetic Device in Fluid using a Single Permanent Magnet with Application in Stomach Capsule Endoscopy," Int. J. Robotics Research, available online.

[3] Ania Servant, Famin Qiu, Mariarosa Mazza, Kostas Kostarelos, Bradley J Nelson , Nanomedicine: Controlled In Vivo Swimming of a Swarm of Bacteria-Like Microrobotic Flagella (Adv. Mater. 19/2015), Advanced Materials 05/2015; 27(19):2949