Propulsion of magnetic microrobots in the vascular vessels of lower limbs: preliminary study

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INTRODUCTION

Cardiovascular disease

Catheter-based procedures

Microbots [1]

Objectives: to demonstrate the feasibility of a coils-based platform to move a magnetic microrobot inside vascular vessels of lower limb. If feasible, coil systems with different geometries - but based on the same propulsion concept - could be also used for navigating in other vascular districts.

METHODS

Helmholtz coils

\[ R_{\text{mean}} = d \rightarrow \text{a highly-uniform magnetic field in the workspace} \]

\[ |B_0| = \frac{8 \mu_0 N l}{r_h} = k l \]

Maxwell coils

\[ v3R_{\text{mean}} = d \rightarrow \text{a highly-uniform magnetic field gradient along the main axes} \]

\[ |\nabla B| = \frac{48}{45} \frac{\mu_0 N l}{r_h^2} = g l \]

Microrobot

\[ \Phi_{\text{mic}} = 4 \text{ mm} \]

\[ h_{\text{mic}} = 10 \text{ mm} \]

\[ m_{\text{mic}} = 0.20 \text{ g} \]

Magnet

Type N48 = 1.38 T

\[ \Phi_{\text{ext}} = 7 \text{ mm} \]

\[ V_{\text{mic}} = 5.495 \text{ mm}^3 \]

Forces and Torques Model

\[ \begin{align*}
\dot{m}p &= F_{\text{drag}} + F_{\text{mag}} + F_{\text{friction}} \\
\dot{m}g &= T_m + T_{\text{drag}} \geq 0
\end{align*} \]

The magnetic microrobot is aligned nearly instantaneously

\[ F_{\text{drag}} = -\mu m g \]

\[ F_{\text{mag}} = \frac{1}{2} \rho C_d \rho^2 \] [3]

\[ C_D = \frac{24}{Re} \frac{6}{1+\sqrt{Re}} + 0.4 \]

\[ T_{\text{drag}} = 8 \pi r^2 \rho \] [4]

\[ B = 0.4 \text{ T} \]

A navigation against the direction of the flow

\[ B = 10 \text{ mT} \]

Fig. 1 The 2 DoF coils system surrounding the lower limb

Fig. 2 A sketch of forces and torques that act on the intravascular microrobot (top) (the coils scale is not realistic)

Table 1: Theoretical properties of the coils composing the magnetic navigation system. The \( R_{\text{ext}}, R_{\text{mic}} \) represent the internal, external and mean radius of the different coils, respectively. The diameter of copper wire for all coils is 0.54 mm

<table>
<thead>
<tr>
<th>Coils</th>
<th>( R_{\text{int}} ) (mm)</th>
<th>( R_{\text{ext}} ) (mm)</th>
<th>( R_{\text{mean}} ) (mm)</th>
<th>( \text{Turns} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helmholtz y</td>
<td>158.1</td>
<td>163.5</td>
<td>160.8</td>
<td>200</td>
</tr>
<tr>
<td>Maxwell y</td>
<td>68.44</td>
<td>153.76</td>
<td>111.1</td>
<td>3160</td>
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<tr>
<td>Helmholtz x</td>
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<td>355</td>
<td>362.29</td>
<td>810</td>
</tr>
<tr>
<td>Maxwell x</td>
<td>150</td>
<td>312</td>
<td>231</td>
<td>9000</td>
</tr>
</tbody>
</table>

How can physicians control the microrobot? Controlling the currents inside the coils by [5]

- Teleoperated control
- Autonomous control

DISCUSSION AND CONCLUSION

- This work proposes a novel magnetic propulsion platform for the 2 DoF steering of magnetic microrobots in the cardiovascular system.
- We are designing an electromagnetic platform to perform an experimental validation in a cardiovascular phantom.
- Finally we will investigate the possibility of 3 DoF navigation by designing an electromagnetic platform acting also in the third direction.

In conclusion, we believe that the intravascular microrobots controlled by external magnetic field produced by coil systems could open new scenarios in cardiovascular procedures.

REFERENCES


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