Available Online: 7 April 2026 DOI: 10.54254/2977-3903/2026.32573

A simulation framework for magnetic actuation and contact mechanics evaluation of magnetic soft robots

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Abstract. Magnetic Soft Robots (MSRs) have shown considerable promise in biomedical applications owing to their flexibility, magnetic controllability, and drug delivery capability. However, the feasibility of their operation depends critically on magnetic drive performance, drug delivery stability, interventional reliability, and safety of contact with blood vessel walls. To address these challenges, this paper proposes a simulation framework for magnetic actuation and contact mechanics evaluation of MSRs. The structural composition and material properties of the MSRs are first defined, along with the parameters of a simplified vessel wall model. A magnetic–structure coupling framework is then constructed, within which the coupling solution strategy and contact simulation method are determined. Deformation behaviors under uniform and nonuniform magnetic fields are verified via simulation, and variations in stress and contact pressure during vessel interaction are analyzed. Finally, the effectiveness and limitations of the framework are summarized. This framework offers theoretical support for structural design, performance optimization, and interventional operation of MSRs, and can be flexibly adapted to different configurations to improve design efficiency and reliability.

Keywords: magnetic soft robots, simulation, magnetic actuation, contact mechanics, magnetic–structure coupling

1. Introduction

In the field of biomedical engineering, the rapid development of microrobot technology has provided new solutions for minimally invasive surgery, drug delivery, lesion monitoring, and other precision medical tasks. This is particularly true in the field of vascular interventional treatment, where traditional rigid interventional instruments suffer from insufficient flexibility, operational difficulty, and a tendency to damage vessel walls, making them ill-suited for narrow and tortuous vascular lumens [1]. Magnetic Soft Robots (MSRs), as a new type of intelligent actuator, combine the flexible deformation characteristics of soft materials with the remote controllability of magnetic actuation [2]. They can flexibly adapt to the complex luminal environment within the body, enabling precise positioning and interventional operations while avoiding the drawbacks of traditional instruments. Additionally, they possess drug delivery capabilities, allowing targeted drug delivery to be achieved alongside interventional procedures [3]. This feature further expands their application scenarios in the biomedical field, making them a current research hotspot in biomedical robotics. In clinical practice, high demands are placed on the magnetic actuation accuracy, flexible deformation capability, drug delivery

stability, interventional operation reliability, and safety of contact with vessel walls of MSRs. Magnetic actuation performance and contact mechanics characteristics are the core indicators determining the feasibility of their clinical application. Therefore, establishing a systematic and efficient simulation framework for evaluating magnetic actuation and contact mechanics is of significant practical importance for advancing the clinical translation of MSRs.

Current research by scholars both domestically and internationally has addressed the magnetic actuation mechanisms and contact mechanics characteristics of MSRs to some extent. However, several challenges remain in numerical simulation. On one hand, existing studies often focus on the performance analysis of single-configuration MSRs, lacking a general simulation evaluation framework capable of adapting to the performance evaluation needs of different structures and application scenarios. The versatility and extensibility of simulation models are therefore limited [4]. On the other hand, the accurate simulation of magnetic–structure coupling effects, the appropriate setting of contact mechanics parameters, and the validation of simulation results against experimental data remain key issues constraining the accuracy of MSR simulations [5]. Furthermore, the contact process between an MSR and a vessel wall is a complex multi-physics coupling problem, where factors such as the elastic response of the vessel wall and contact friction effects interact with one another. Meanwhile, the deformation stability of the MSR during drug delivery can also affect the drug release outcome, further increasing the difficulty of numerical simulation. A comprehensive simulation framework is urgently needed to address these issues.

This paper aims to propose a general simulation framework for magnetic actuation and contact mechanics evaluation of MSRs, designed to overcome the issues of strong specificity, poor generality, and insufficient accuracy in existing simulation methods. The core of the research revolves around model construction, simulation framework development, mechanical evaluation, and result validation. All simulation experiments are conducted using COMSOL Multiphysics software, leveraging its powerful multi-physics coupling capabilities to achieve accurate simulation of magnetic–structure coupling and contact mechanics characteristics. First, the structural and material properties of typical MSR configurations and the parameters of a simplified vessel wall model are defined, leading to the construction of a general magnetic–structure coupling simulation framework. A systematic contact mechanics evaluation method is also established, addressing both the interventional operation and drug delivery requirements of MSRs. Subsequently, through case validation using several typical MSR configurations, the deformation behavior of MSRs under different magnetic fields and the contact mechanics characteristics of the vessel wall are systematically analyzed. The simulation results are validated against relevant literature data, providing reliable support for the structural design, performance optimization, interventional operation safety, and drug delivery stability of MSRs.

The remainder of this paper is structured as follows: Section 2 describes the model composition and magnetic actuation principles of MSRs, including their structural materials and core magnetic actuation mechanisms. Section 3 presents the construction of the simulation framework and coupling strategy, outlining the overall workflow, coupling solution approach, and contact mechanics evaluation method. Section 4 presents case validation, analyzing the deformation behavior of MSRs under different magnetic fields and the contact mechanics characteristics of the vessel wall. Section 5 summarizes the core contributions, discusses limitations, and suggests directions for future work.

2. Model composition and principles of magnetic actuation

2.1. Structure and materials of MSR

The structural design and material properties of MSRs directly determine their magnetic actuation performance, flexible deformation capability, interventional operation reliability, and drug delivery stability. This study selects six typical configurations of MSRs (MSR-1 to MSR-6) [6-8], with their specific geometries shown in Figure 1. The material composition of these six MSR configurations includes a flexible substrate and NdFeB magnets. The flexible substrate is made of commonly used flexible materials such as PDMS, Ecoflex, Vytaflex, or Dragon Skin. Such materials offer good flexibility, biocompatibility, and chemical stability. They not only meet the deformation requirements of MSRs in biological environments and adapt to the luminal conditions encountered during interventional procedures, but also serve as drug carriers, enabling stable drug loading and delivery. Their mechanical property parameters have been experimentally validated, ensuring accurate matching to simulation requirements. NdFeB serves as the magnetic response unit, endowing MSRs with magnetic actuation capabilities that enable deformation and movement under an external magnetic field, thereby achieving precise control over interventional positioning and drug delivery. Its magnetic property parameters (e.g., magnetization intensity, remanence) are selected based on practical application requirements to ensure accurate magnetic actuation response, providing a foundation for setting magnetic field parameters in subsequent simulations.

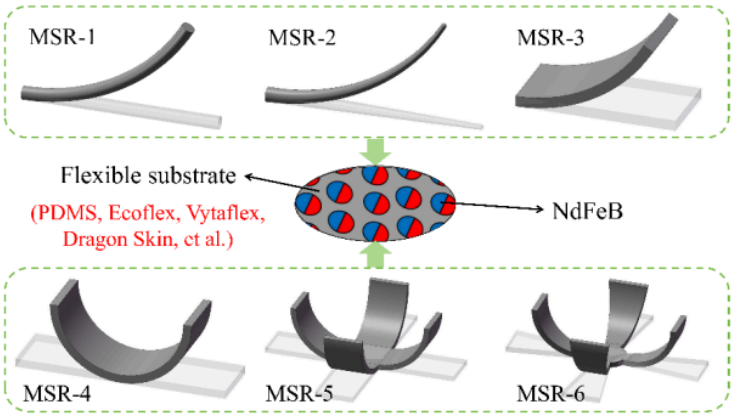

Figure 1. Typical configuration of magnetic soft robots

2.2. Simplified model of blood vessel wall

To accurately simulate the contact mechanics characteristics during the interventional propulsion of MSRs while balancing simulation accuracy and computational efficiency, a reasonable simplification of the human vessel wall is performed, and a simulation model is constructed (as shown in Figure 2). This model includes a vascular axis and a vascular wall. The vascular axis can be flexibly defined and adjusted according to the research needs of different scholars. The vessel wall thickness is set to t = 0.5 mm. The simplified vessel wall model is constructed using a homogeneous, isotropic elastic material, with geometric dimensions adapted to the MSR interventional scenario. The multilayer structural differences and physiological textures of the vessel wall are neglected, with a focus on retaining the core elastic properties. The key mechanical parameters are set as follows: elastic modulus 0.3 MPa, Poisson's ratio 0.45 [9]. These parameters are determined with reference to experimental data from human small arteries and accurately reflect the elastic response of the vessel wall. This provides a reliable foundation for the contact mechanics simulation between the MSR and the vessel

wall, while connecting the MSR model described earlier with the subsequent magnetic actuation and contact simulations, forming a complete logical chain. All parameters are set in accordance with COMSOL simulation requirements, ensuring the model can be directly used in subsequent simulation calculations.

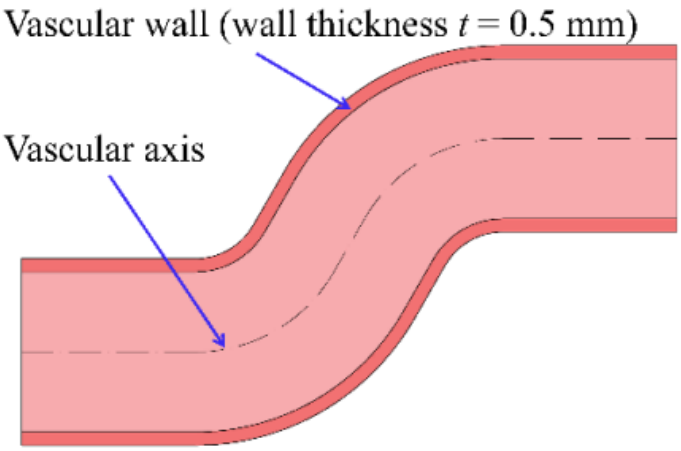

Figure 2. Simplified vascular model

2.3. Principles of magnetic actuation

The magnetic actuation principle of MSRs is based on the effect of a magnetic field on the magnetic units within the robot. When an external magnetic field B acts on an MSR, the magnetic units inside experience a magnetic force F and a magnetic torque τ [10], which drive the MSR to undergo flexible deformation, enabling precise positioning for interventional operations, motion control, and stable propulsion for drug delivery. A schematic diagram of the magnetic actuation principle is shown in Figure 3, where the magnetization M of the MSR is clearly indicated, visually demonstrating the magnetization state of the MSR in the magnetic field. The magnetic torque τ and magnetic force F experienced by the MSR in the magnetic field are given by the following equations:

$$\tau = VM \times B \tag{1}$$

$$F = V(M \cdot \nabla)B \tag{2}$$

where V is the volume of the MSR.

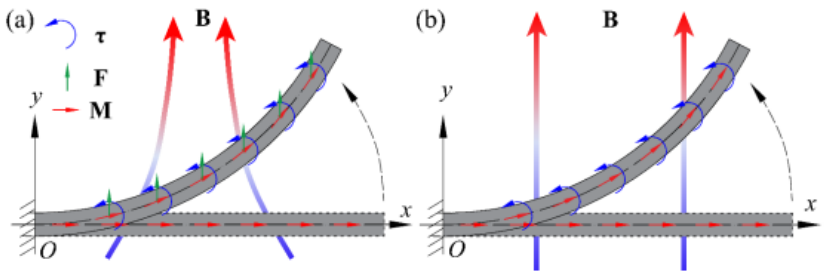

Figure 3. Schematic diagram of the principle of magnetic field B actuating MSR
(a) In a non-uniform magnetic field; (b) In a uniform magnetic field

The actuation effects of uniform and non-uniform magnetic fields on MSRs differ significantly, and these differences directly affect the interventional operation outcome and drug delivery stability of the MSR. In a

non-uniform magnetic field (as shown in Figure 3(a)), both the magnetic force F and magnetic torque τ acting on the MSR serve as the primary drivers for translation and deformation. The distribution of the magnetic field gradient directly affects the magnitude and direction of the magnetic force, thereby determining the propulsion speed and degree of deformation of the MSR. In a uniform magnetic field (as shown in Figure 3(b)), the magnetic torque τ plays a dominant role, driving the MSR to rotate and bend. The magnitude of the magnetization M determines the strength of the magnetic torque, which in turn influences the amplitude of the MSR's deformation, allowing it to flexibly adapt to curved sections of blood vessels and achieve precise positioning. A fundamental coupling relationship exists between the magnetic load and the structural deformation. The magnetic load applied by the external magnetic field induces flexible deformation in the MSR, and the subsequent change in the MSR's magnetization state affects the magnetic force and torque it experiences. This coupling relationship forms the core basis for magnetic–structure coupling simulation and is key to accurately simulating the magnetic actuation performance and stability of MSRs. The subsequent simulation will achieve accurate modeling of this coupling effect using COMSOL software.

3. Simulation framework and coupling strategy

3.1. Overall simulation process

The simulation framework for magnetic actuation and contact mechanics evaluation of MSRs proposed in this paper is built using COMSOL Multiphysics software. It follows the core workflow (as shown in Figure 4) of "pre-processing – solver setup – post-processing," enabling systematic evaluation of the magnetic actuation performance, interventional operation reliability, drug delivery stability, and contact mechanics characteristics of MSRs, thereby supporting their structural design and optimization. In the pre-processing stage, the geometric model is imported, material parameters are assigned, boundary conditions are applied, and meshing is performed, balancing simulation accuracy and computational efficiency. The solver is set to steady-state mode with the magnetic–structure multi-physics coupling enabled. In the post-processing stage, simulation data are extracted, visualization nephograms are generated, and deformation and contact mechanics characteristics are analyzed. It should be noted that this simulation focuses on the mechanical evaluation of MSRs during vascular propulsion and does not include the dynamic details of magnetic actuation. The analysis primarily focuses on the effects of deformation and contact characteristics on interventional operation and drug delivery.

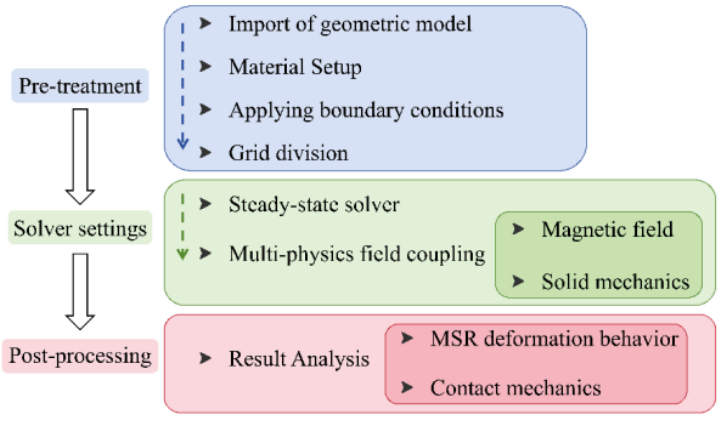

Figure 4. Simulation framework diagram

3.2. Magnetic-structure coupling solution scheme

Magnetic–structure coupling is central to MSR simulation and directly influences the accuracy of simulation results, which in turn affects the assessment of interventional operation precision, drug delivery stability, and contact safety. In this study, a magnetic–structure coupling simulation model of MSRs is constructed using the finite element method within COMSOL Multiphysics software. The geometric construction is shown in Figure 5. This figure illustrates the three-dimensional geometric models of the MSR and the magnetic field, as well as the boundary conditions of the simulation domain, providing a clear overview of the overall simulation model structure. The core of the magnetic–structure coupling solution lies in transferring the magnetic load into a structural mechanics response. By leveraging the multi-physics coupling solver in COMSOL, a two-way coupling solution can be achieved, ensuring the accuracy of the simulation results.

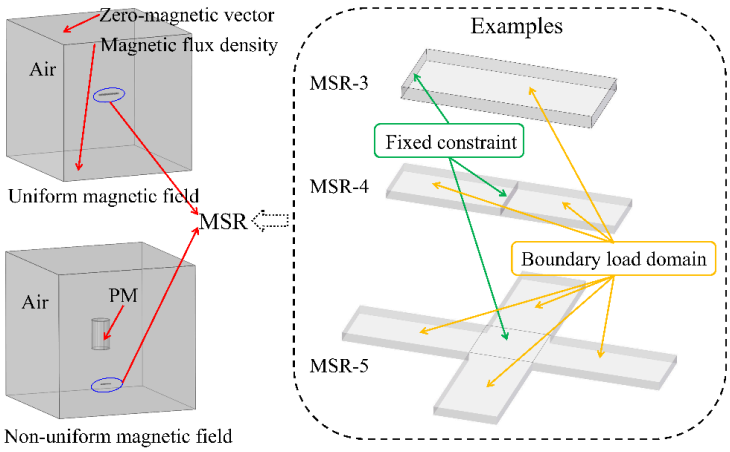

Figure 5. Geometric construction of the MSR simulation model

Specifically, the magnetic force and torque experienced by the MSR under the applied external magnetic field are first calculated using the magnetic field module. These are then applied as loads to the MSR model in the structural mechanics simulation. Subsequently, the structural deformation and stress distribution of the MSR are solved using the structural mechanics module, while accounting for the effect of deformation on the magnetic field distribution, thereby achieving a two-way coupled solution. The primary purpose of the coupled solution is to analyze the deformation effect of the MSR under magnetic actuation, obtaining key parameters such as deformation magnitude and deformation pattern. This provides a solid foundation for evaluating interventional operation, drug delivery, and vessel wall mechanics. The magnetic field in the simulation model includes both uniform and non-uniform types, where the non-uniform magnetic field is generated by a Permanent Magnet (PM). Boundary conditions are set using MSR-3, MSR-4, and MSR-5 as examples, with constraints and magnetic loads defined according to the configuration characteristics of the MSRs and the motion requirements for interventional operation and drug delivery, ensuring that the simulation process reflects real-world operational scenarios.

3.3. Contact behavior simulation and mechanical evaluation method

This study focuses on simulating the contact between an MSR and the vessel wall during interventional propulsion. The core analysis involves the mechanical characteristics of the vessel wall during this contact process, providing a theoretical basis for evaluating the clinical safety, interventional operation reliability, and

drug delivery efficacy of MSRs. MSR-2 is used as an example for conducting the contact behavior simulation and establishing the mechanical evaluation method; simulations for other MSR configurations can refer to this approach. The geometric construction of the simulation model for the contact behavior of MSR-2 with the vessel is shown in Figure 6. In the contact behavior simulation, the coefficient of friction significantly affects the simulation results of contact mechanics. Considering the contact characteristics between the flexible MSR material and the vessel wall, as well as the contact stability requirements during drug delivery, the friction coefficient is set to 0.2 [9] in this simulation. This setting is used to model the frictional interaction between the two surfaces, ensuring the accuracy of the contact simulation and preventing simulation errors due to improper friction settings that could affect the evaluation of interventional operation and drug delivery.

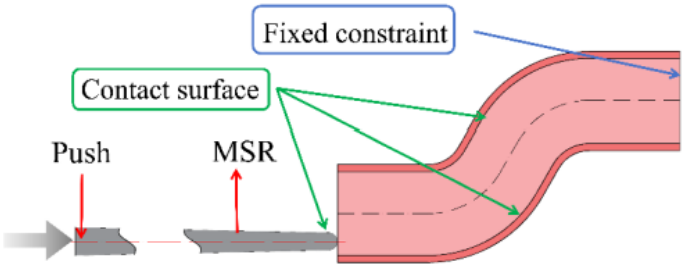

Figure 6. The geometric construction of the simulation model for the contact behavior of the MSR-2 device with blood vessels

The mechanical evaluation method uses the vessel wall contact pressure and stress as the core evaluation metrics. The contact pressure data during the contact process between MSR-2 and the vessel wall is extracted using the software's post-processing module, and the variation of contact pressure with propulsion distance is recorded. The stress evaluation focuses on the distribution characteristics and magnitude of the stress on the vessel wall. The evaluation criterion is whether the vessel wall stress remains within the safe threshold for human blood vessels. By analyzing the stress nephograms, regions of stress concentration on the vessel wall are identified, allowing assessment of whether the MSR propulsion process may cause damage to the vessel wall, thereby ensuring the safety of interventional operation and the stability of drug delivery. Additionally, this simulation framework can incorporate magnetic actuation conditions. By utilizing the magnetic–structure coupling function, the contact effect of the robot on the vessel wall under magnetic actuation can be observed. This provides opportunities for further research related to interventional operation optimization and drug delivery system improvement for MSRs, further enhancing the generality and practicality of the framework.

4. Example verification and result analysis

4.1. Robot deformation behavior under uniform magnetic field

To verify the deformation characteristics of MSRs under a uniform magnetic field and clarify their magnetic actuation response, simulation experiments are conducted using MSR-3 and MSR-4 as representative cases. In both experiments, the magnetic field strength is set to 50 mT. The simulation results are shown in Figure 7(a) and Figure 8. The simulation results in Figure 7(a) show that under a uniform magnetic field of 50 mT, MSR-3 undergoes obvious flexible deformation with a displacement of 20.40 mm. The deformation is uniform and consistent with expectations for magnetic actuation. Such uniform deformation helps ensure that the MSR does not cause damage to the vessel wall due to localized excessive deformation during interventional

propulsion within the vessel, thus supporting its use in vascular interventional procedures. Figure 8 shows that MSR-4, also under a uniform magnetic field of 50 mT, achieves a displacement of 20.60 mm. Compared with MSR-3, the deformation pattern and displacement magnitude differ slightly due to configuration differences, but the overall deformation behavior is consistent, with both exhibiting good magnetic actuation response. This indicates that different typical configurations of MSRs can achieve stable deformation under a uniform magnetic field, meeting the needs of various interventional scenarios and drug delivery requirements, and validates the adaptability of the simulation framework developed in this study to different MSR configurations.

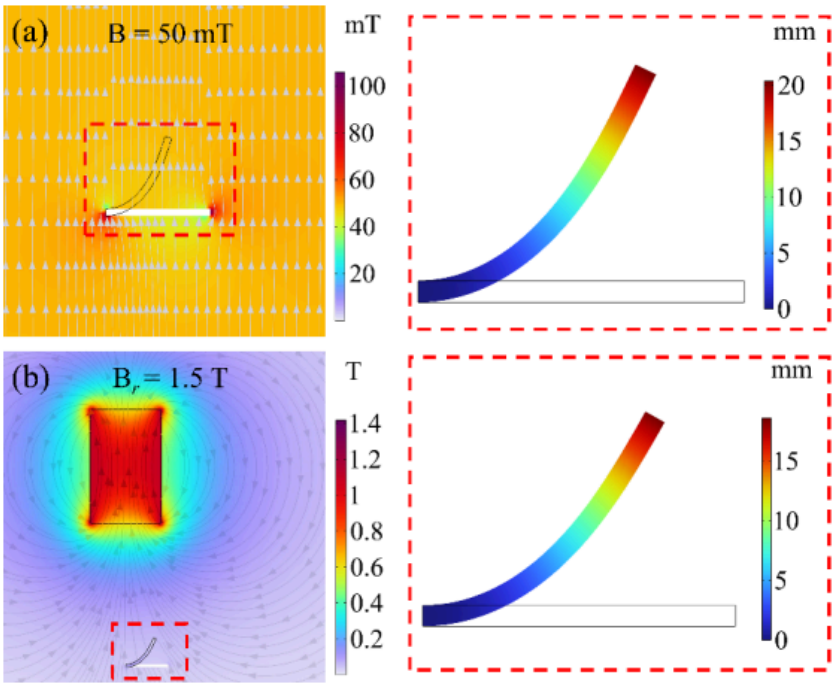

Figure 7. The deformation behavior of MSR-3 under uniform magnetic field and non-uniform magnetic field (a) In a uniform magnetic field: spatial magnetic flux density (Left) and displacement nephograms (Right); (b) In a non-uniform magnetic field: spatial magnetic flux density (Left) and displacement nephograms (Right)

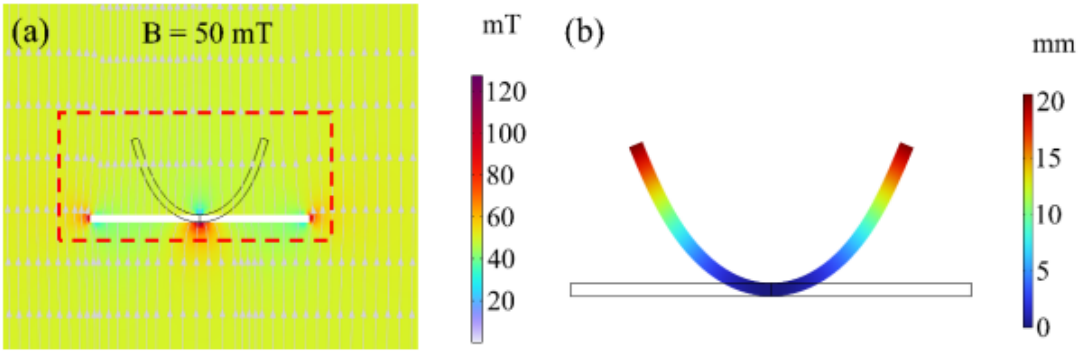

Figure 8. The deformation behavior of MSR-4 under a uniform magnetic field
(a) Spatial magnetic flux density nephogram; (b) Displacement nephogram

4.2. Robot deformation behavior under non-uniform magnetic field

The deformation behavior of MSR-3 under a non-uniform magnetic field is investigated through simulation. The objective is to compare the deformation of MSR-3 under uniform and non-uniform magnetic fields, analyzing the influence of the non-uniform field on the robot's deformation pattern, interventional propulsion posture, and drug delivery stability. The non-uniform magnetic field is generated by a PM with remanence B_r = 1.4 T. The simulation results are presented in Figure 7(b). The simulation results show that under this non-uniform magnetic field, MSR-3 achieves a displacement of 18.6 mm, which is smaller than that observed under the uniform field (50 mT). This difference is primarily attributed to the distinct magnetic field distributions. Furthermore, under the non-uniform magnetic field, the deformation posture of MSR-3 exhibits greater directionality, making it better suited to conform to the curvature of blood vessels and facilitating interventional propulsion through complex vascular lumens. Simultaneously, the stable deformation posture helps maintain the integrity of the drug delivery carrier, preventing drug leakage due to excessive deformation. This further validates the significant influence of magnetic field type on the deformation behavior, interventional operation effectiveness, and drug delivery stability of MSRs, providing a reference for future work on optimizing magnetic actuation control strategies for MSRs.

4.3. Vascular wall contact force and stress analysis

Simulation experiments are conducted using MSR-2 as the subject to investigate its contact with the vessel wall during interventional propulsion. The purpose is to present the simulated vessel wall contact force, stress distribution, and stress magnitude, analyze the stress distribution pattern, and evaluate the mechanical impact of the robot's interventional propulsion process on the vessel wall. The simulation results are shown in Figures 9 and 10. In this simulation, the total propulsion distance l of MSR-2 is 26 mm, with a propulsion step size of 2 mm. Contact between MSR-2 and the vessel wall begins at l = 12 mm; therefore, the analysis focuses on the contact mechanics characteristics of the vessel wall in the range l = 12~26 mm.

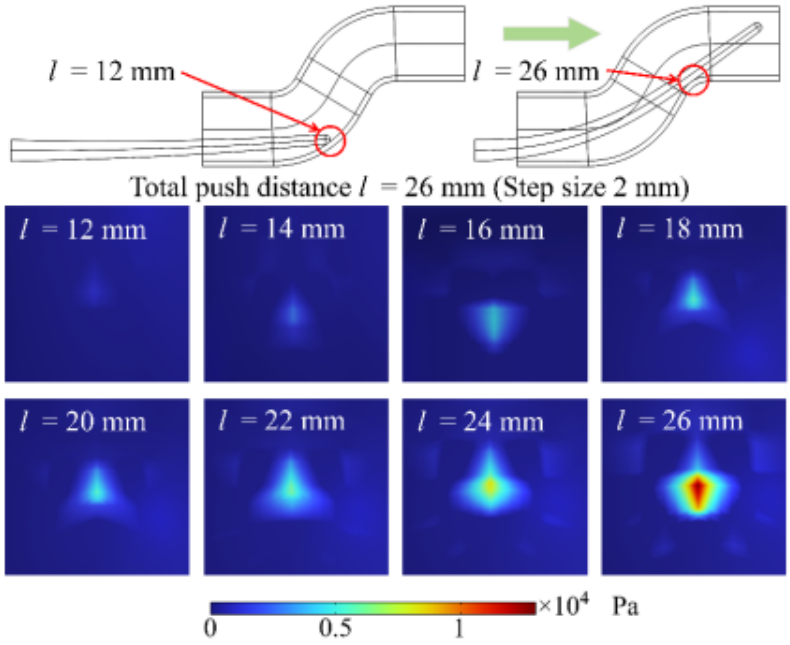

Figure 9. Stress nephograms of the vascular wall during the MSR-2 propulsion process (l = 12~26 mm)

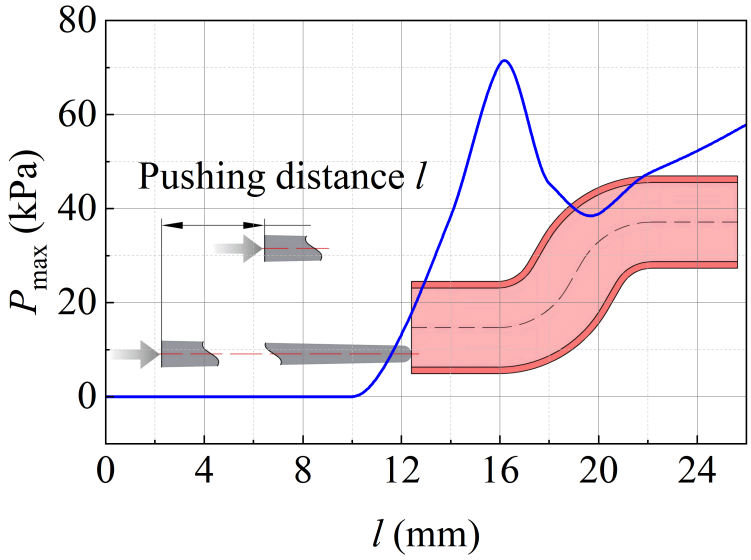

Figure 10. The relationship between the maximum contact pressure Pmax between the MSR-2 tip and the vessel wall and the pushing distance l

Figure 9 presents the stress nephograms of the vessel wall during the propulsion of MSR-2. It can be observed from the figure that as the propulsion distance l increases, the stress at the contact point on the vessel wall exhibits a monotonic increasing trend. When the propulsion distance l reaches 26 mm, the maximum stress on the vessel wall reaches 1.31×10^3 Pa.

Figure 10 shows the variation of the maximum contact pressure P_{max} between the tip of MSR-2 and the vessel wall as a function of propulsion distance l. The curve indicates that as $l$increases, P_{max} initially increases, then decreases, and subsequently increases again, with the maximum contact pressure occurring at l = 16 mm. This trend is closely related to the deformation pattern of MSR-2, the elastic response of the vessel wall, and changes in the contact position. It reflects the dynamic mechanical characteristics of the contact between MSR-2 and the vessel wall during interventional propulsion, providing data to support the control of interventional propulsion force and the optimization of drug delivery stability for MSRs.

5. Conclusion

The conclusion should elaborate on the key points of the research results, analyze the conclusions drawn from the results, and explain their significance for future research or practice. All sections such as patents, appendices, funding projects, and acknowledgments should be placed after the conclusion and before the references.

This paper presents research on the magnetic actuation and contact mechanics evaluation of MSRs, with emphasis on the requirements for interventional operation safety and drug delivery stability. All simulation experiments are conducted using COMSOL Multiphysics software, leveraging its multi-physics coupling and contact mechanics simulation capabilities to achieve accurate evaluation of the magnetic actuation performance and contact mechanics characteristics of MSRs. The core work completed in this study includes model construction of MSRs, development of a simulation framework, and mechanical evaluation. By defining the structural material properties of MSRs and the parameters of a simplified vessel wall model, a general magnetic–structure coupling simulation framework is constructed, and a mechanical evaluation method centered on vessel wall contact force and stress is established. Furthermore, through case validation

using multiple MSR configurations, the deformation behavior of MSRs under different magnetic fields and the contact mechanics characteristics of the vessel wall are systematically analyzed, demonstrating the practicality of the simulation framework. This work provides reliable theoretical support and a simulation tool for the structural design, performance optimization, interventional operation reliability, and drug delivery stability of MSRs.

This study has certain limitations that can be addressed in future work:

The simulation focuses on the mechanical characteristics during MSR vascular propulsion and does not include the dynamic details of magnetic actuation. As a result, it cannot fully simulate the dynamic motion process of MSRs during interventional operation and drug delivery in actual vascular environments.

The contact mechanics evaluation is validated using MSR-2 as a typical configuration. Although the contact mechanics characteristics of different MSR configurations share commonalities, not all typical configurations have been validated. Future work can expand the validation scope to further enhance the generality of the framework.

The simulation model does not account for the influence of complex environmental factors such as blood flow and temperature changes within the body, so the simulation results may deviate to some extent from real clinical scenarios.

Future research can focus on the following areas: optimizing the simulation framework by incorporating dynamic details of magnetic actuation, further improving the multi-physics coupling simulation capabilities within COMSOL to more accurately model the dynamic processes of MSR interventional operation and drug delivery; expanding the scope of case validation by developing a comprehensive validation system that accounts for the common characteristics of various MSR configurations, thereby enhancing the framework's generality; and incorporating complex environmental factors such as blood flow and temperature variations into the simulation model within the software. These improvements will facilitate the practical application of MSRs in clinical settings and contribute to a more comprehensive research system.

References

[1] Pore, A., Li, Z., Dall'Alba, D., Hernansanz, A., De Momi, E., Menciassi, A., & Vander Poorten, E. (2023).Autonomous navigation for robot-assisted intraluminal and endovascular procedures: A systematic review.*IEEE Transactions on Robotics, 39*(4), 2529-2548. https: //doi.org/10.1109/tro.2023.3269384

[2] Bira, N., Dhagat, P., & Davidson, J. R. (2020). A review of magnetic elastomers and their role in softrobotics. *Frontiers in Robotics and AI, 7*, 588391. https: //doi.org/10.3389/frobt.2020.588391

[3] Lee, Y., Koehler, F., Dillon, T., Loke, G., Kim, Y., Marion, J., & Anikeeva, P. (2023). Magneticallyactuated fiber-based soft robots. *Advanced Materials, 35*(38), 2301916.https: //doi.org/10.1002/adma.202301916

[4] Davy, J., Lloyd, P., Chandler, J. H., & Valdastri, P. (2023). A framework for simulation of magnetic softrobots using the material point method. *IEEE Robotics and Automation Letters, 8*(6), 3470-3477.https: //doi.org/10.1109/lra.2023.3268016

[5] Tong, D., Hao, Z., Li, J., Sun, B., Liu, M., Wang, L., & Huang, W. (2025). Real-time simulation enablednavigation control of magnetic soft continuum robots in confined lumens. *Journal of the Mechanics andPhysics of Solids, 203*, 106198. https: //doi.org/10.1016/j.jmps.2025.106198

[6] Lu, L., Sim, J., & Zhao, R. R. (2024). Mechanics of hard-magnetic soft materials: A review. *Mechanics of Materials, 189*, 104874. https: //doi.org/10.1016/j.mechmat.2023.104874

[7] Murakami, T., & Tsumori, F. (2022). Magnetic driven tentacles for bio-mimic motion. *Japanese Journalof Applied Physics, 61*(SD), SD1014. https: //doi.org/10.35848/1347-4065/ac5a99

[8] Dai, Y., Liang, S., Chen, Y., Feng, Y., Chen, D., Song, B., & Arai, F. (2020). Untethered octopus-inspiredmillirobot actuated by regular tetrahedron arranged magnetic field. *Advanced Intelligent Systems, 2*(5), 1900148. https: //doi.org/10.1002/aisy.202070053

[9] Li, J., Chen, H., & Wang, L. (2024). Model-guided navigation of magnetic soft guidewire for safeendovascular surgery. *Journal of the Mechanics and Physics of Solids, 190*, 105731.https: //doi.org/10.1016/j.jmps.2024.105731

[10] Wang, Y., Shen, J., Handschuh-Wang, S., Qiu, M., Du, S., & Wang, B. (2022). Microrobots for targeteddelivery and therapy in digestive system. *ACS nano, 17*(1), 27-50.https: //doi.org/10.1021/acsnano.2c04716