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The large, viscous thrombus is aspirated by using the cyclic suction technique

Shenqi Lin [a], Ling Yu [b*], Ruiting Hong [c], Runcheng Dong [d], Bohao Liu [e], Wencong Ruan [f], Tao Sun [g], Dongqing Zhou [h], Yixuan Zhou [i], Shi Chen [j]

Shanghai Jian Qiao University, Shanghai, 201306, China

Abstract: With the development of socio-economic conditions and changes in people's lifestyles, particularly the acceleration of population aging and urbanization, unhealthy living habits among residents have become increasingly prominent. Cardiovascular disease (CVD) risk factors have a growing impact on public health, and the incidence of CVD continues to rise. Current research focuses mainly on improving the safety and effectiveness of thrombectomy devices and reducing complications during surgical procedures. Additionally, researchers are exploring the application of these devices in specific patient groups, such as those with comorbid conditions. This project introduces an intelligent device based on an MCU (Microcontroller Unit). Starting with the overall hardware system design, it includes the development of the device casing, selection of the MCU, and design of the internal pipeline length according to the pressure tolerance of the human inferior vena cava during thrombectomy. A pressure control valve and a pressure gauge are installed to ensure that the suction pressure remains within a safe range tolerable for the human body throughout the procedure. Pressure sensor data is then used to develop algorithms and control programs, enabling precise control of the opening and closing actions of the positive and negative pressure solenoid valves at specified intervals. By using optimal timing data, the suction tube of the device can generate impacts to break large thrombi while effectively preventing them from escaping to other parts of the vessel during the suction process, ensuring the smooth completion of thrombectomy. Through its unique design and precise operation, this device can more effectively remove thrombi from blood vessels, overcoming the limitations and risks of traditional treatment methods. This technological innovation not only advances the overall technical capabilities of the medical industry but also provides physicians with a more efficient and convenient treatment tool, further improving the quality and efficiency of medical services. Moreover, by rapidly and effectively removing thrombi, this treatment reduces patient hospitalization time and medication use, thereby lowering medical costs. As the technology becomes more widespread and its application more common, the cost of this treatment method is expected to decrease further, providing more patients with an affordable and effective treatment option.

1 Introduction

1.1 Research Background and Significance

With the development of socioeconomics, changes in national lifestyles, and particularly the acceleration of population aging and urbanization, unhealthy lifestyles among residents have become increasingly prevalent. The impact of cardiovascular disease risk factors on public health has grown significantly, and the incidence of cardiovascular diseases continues to rise. Due to continuous advancements in medical technology and the intensification of population aging, the cost of diagnosing and treating cardiovascular diseases has been steadily increasing, imposing a substantial financial burden on both national budgets and household economies. Pulmonary thromboembolism (PTE) emboli often originate from venous thrombosis in the limbs, especially deep vein thrombosis (DVT) of the lower limbs, making the examination of lower limb deep veins particularly important [1-3]. The presence of thrombi not only disrupts normal blood flow but can also lead to vascular occlusion in severe cases, posing a life-threatening risk to patients. Thrombectomy devices play a crucial role in the treatment of cardiovascular diseases, particularly in obstructive conditions such as myocardial infarction and acute lower limb deep vein thrombosis. These devices can rapidly remove thrombi from coronary and deep veins, restore blood flow, and reduce myocardial damage. Current research primarily focuses on improving the safety and

[a]1483450285@qq.com; [b]lingyu@gench.edu.cn
[c]1433023471@qq.com; [d]17846344320@163.com
[e]Husl1233@outlook.com; [k]3087227975@qq.com
[g]1990237126@qq.com; [h]2020486467@qq.com
[i]1137952060@qq.com; [j]13641988397@163.com

effectiveness of thrombectomy devices and minimizing complications during procedures. Additionally, researchers are exploring the application of thrombectomy devices in special patient groups, such as those with comorbidities, to evaluate their efficacy and safety [4-7].

1.2 Research Content and Innovations

This project implements an intelligent device based on an MCU, starting from the overall hardware system design of the thrombus aspiration device (hereafter referred to as the "device"). It includes the design of the device casing and the selection of the MCU. According to the pressure tolerance requirements of the human inferior vena cava during the thrombus aspiration process, the internal pipeline length of the device is designed, and a pressure control valve and pressure gauge are installed to ensure that the suction pressure remains within the safety range tolerable by the human body throughout the procedure. Furthermore, relevant algorithms and control programs are developed based on data from the pressure sensor to control the opening and closing of the positive and negative pressure solenoid valves at specified time intervals. By using the optimal time interval data, the device's aspiration tube can generate impactful forces to break down large thrombi while effectively preventing thrombus fragments from escaping to other parts of the blood vessel during aspiration, ensuring the successful completion of the thrombus removal task.

2 Theoretical Analysis and System Design

The key challenge of this design is to achieve accurate detection of the thrombus location within the human blood vessels and to minimize blood loss during the thrombus aspiration process. Therefore, the primary task is to conduct a feasibility and applicability analysis of the pressure sensor measurement algorithm used in this design to detect whether the thrombus is obstructing the blood vessel.

2.1 Design and Feasibility Analysis of the Circulatory Aspiration System.

Regarding the detection scheme for thrombus in human blood vessels, two solutions were finalized after theoretical analysis: ① When an embolus in the blood vessel blocks the suction tube's inlet, the pressure value at the inlet of the device's suction tube will change significantly compared to when the inlet is not blocked. Based on this, a customized pressure sensor is used to detect the pressure at the suction tube's port to determine if the thrombus is blocking the tube, and subsequently, whether there is an embolus obstructing the vessel at that location. ② When an embolus blocks the blood vessel, the blood flow velocity will slow down compared to when the vessel is not blocked, and the blood flow rate through a certain section will also decrease significantly. Based on this, a flow sensor is used to detect the blood flow velocity and flow rate at a certain location, and by comparing the measured values with standard values, it can be determined whether there is an embolus in that section of the blood vessel.

In the experiment using Solution 1, the first step is to configure the environment for the suction device. When the thrombus aspiration device is in a non-operational state and the suction tube is connected to the external environment, the pressure measured by the pressure gauge is the current atmospheric pressure. When the device is in detection or suction mode (i.e., operational state), the negative pressure pump starts working, generating negative pressure. The device assumes that the thrombus aspiration tube has entered the human blood vessel, and at this point, the pressure gauge displays the specific negative pressure generated by the negative pressure pump, which is the current system pressure of the device. The pressure sensor detects the pressure at the suction tube's port. The system pressure required for both suction and thrombus detection must be maintained between -85kPa and -90kPa.

2.2 Overall System Framework Design

Working Principle: The overall device is equipped with a main switch at the power supply. Once pressed, the negative pressure machine starts operating, generating negative pressure, and powering all loads and sensors in the device's circuit to begin working. The system structure of the device is shown in Figure 1. After the negative pressure machine starts working, it provides a negative pressure environment for the device's suction pipeline to facilitate thrombus aspiration. The pressure displayed by the pressure gauge indicates the pressure value in the negative pressure pipeline when the device is not in operation. The negative pressure valve is a single-head valve, and when it operates, its armature only clamps the negative pressure pipeline. The liquid in the positive pressure infusion bag is blood with the same blood type as the patient's, used to provide a positive pressure environment for the suction pipeline during thrombus aspiration. The positive pressure valve is a double-head valve, and during operation, its armature either clamps the positive pressure pipeline or the negative pressure pipeline, enabling alternating positive and negative pressure for thrombus aspiration. Sensor 1 is used to detect the pressure status between the two solenoid valves, while Sensor 2 detects the pressure status at the suction tube inlet of the negative pressure pipeline. The liquid storage tank is used to store the embolic material and blood aspirated from the human blood vessel.

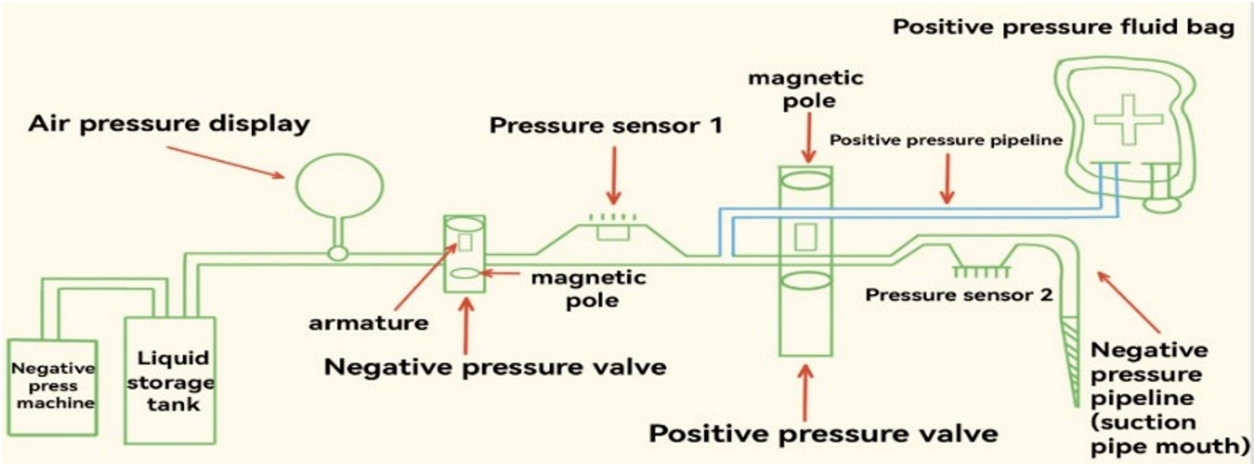

Figure 1. Structure Diagram of the Device System

A classic case was presented by Tiberio Michele Frisoli and colleagues from the Henry Ford Health System in the United States, with their findings published in *JACC: Case Reports* in October 2020. The case involved a 48-year-old male patient who presented to the emergency department approximately 23 hours after the sudden onset of dysarthria and right-sided limb weakness. Upon admission, his vital signs were: blood pressure 142/76 mmHg, heart rate 84 beats per minute, and oxygen saturation 98%.

The treatment utilized the AngioVac system. The input catheter was inserted through the right femoral artery, while the output catheter was positioned in the left femoral vein. The input catheter was advanced into the descending abdominal aorta, with circuit blood flow gradually increased to 3.5 liters per minute to ensure hemodynamic stability. The input catheter was then further advanced to the proximal descending aorta. As it approached the aortic arch, the catheter tip bent and slowly moved toward the thrombus. When the input catheter neared the thrombus, the circuit blood flow increased to 4 liters per minute. After approximately three minutes of aspiration, the thrombus finally detached from the aortic wall. A large portion of the thrombus was securely captured at the tip of the input catheter, leaving small fragments still attached to the aorta [8]. The thrombus and input catheter were subsequently removed together. Histopathological examination confirmed the thrombus to be organized. Cerebral angiography conducted before the conclusion of the intervention revealed normal cerebral blood flow in the head and neck, with no stenosis or occlusion. The removed thrombus measured 6 centimeters in length, classifying it as a large thrombus [9].

3 Conclusion

This chapter presents a comprehensive exploration of the theoretical analysis and feasibility of a thrombus aspiration system designed to accurately detect thrombus locations within human blood vessels and minimize blood loss during the aspiration process. Two detection methods—pressure sensor measurement and flow sensor detection—were considered, with the pressure sensor method selected for its effective thrombus detection and lower cost. The circulatory aspiration system was designed to use pressure sensors to detect blockage in the suction tube and infer the presence of emboli, ensuring safe and effective thrombus removal. The chapter also outlines the system's framework, including its working principle, design structure, and technical approach, establishing a practical pathway for enhancing thrombus aspiration device performance and minimizing complications for patients.

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References

1. Liu Mingbo, He Xinye, Yang Xiaohong, et al. Key Interpretation of the "China Cardiovascular Health and Disease Report 2023" [J]. Chinese Journal of Cardiovascular Disease, 2024, 29(04):305-324.
2. Wang Rui, Wei Daolin, Shi Ruping, et al. Effect of Lower Limb Active Rehabilitation Training Device on Preventing Deep Vein Thrombosis in Elderly Patients After Hip Replacement Surgery [J]. International Journal of Nursing, 2024, 43(04):722-726.
3. Zhao Junlai, Zhao Keqiang, Cao Zhanjiang, et al. Efficacy Analysis of Mechanical Thrombectomy for Acute Lower Limb Venous Thrombosis [J]. Chinese Medical Journal, 2015(48):3.
4. Yin X, Lang D, Wang D. Comparison of mechanical thrombectomy with transcatheter thrombolysis for acute iliac femoral venous thrombosis [J]. Journal of Zhejiang University (Medical Sciences), 2022, 47(6):588-594.
5. Li Jinwang, Xue Jun, Guo Fei, et al. Clinical Comparison Analysis of Systemic Thrombolysis,

Catheter-Directed Thrombolysis, and AngioJet Percutaneous Mechanical Thrombectomy for Acute Lower Limb Deep Vein Thrombosis [J]. Journal of the Chinese Academy of Medical Sciences, 2023, 45(03):410-415.

6. Tian Jinlin, Wang Wei, Li Yunsong, et al. Villalta Scoring and Clinical Application of Post-Thrombotic Syndrome in Lower Limb Deep Vein Thrombosis [J]. Chinese Journal of General Surgery and Clinical Medicine, 2015, 22(04):486-489.
7. Zhou Erhao, Zhang Liwei, Li Xiaolong, et al. Endovenous Interventional Therapy for Acute Lower Limb Deep Vein Thrombosis [J]. Medical Theory and Practice, 2024, 37(10):1655-1657.
8. Lu Qian, Ye Shaowu. Clinical Efficacy of Endovenous Mechanical Thrombus Fragmentation and Thrombolytic Intervention in Acute Lower Limb Deep Vein Thrombosis [J]. Journal of the Chinese People's Liberation Army Preventive Medicine, 2019, 37(10):109-110.
9. Suo Feifei, Li Jingjing, Zhai Gang, et al. AcoStream Thrombectomy System Combined with Catheter-Directed Thrombolysis in the Treatment of Lower Limb Deep Vein Thrombosis with Iliac Vein Compression Syndrome [J]. Chinese Journal of Clinical New Medicine, 2024, 17(08):920-924.